March 14, 2013

WORKING GROUP 3
E9-1-1 Location Accuracy

Report – Leveraging LBS and Emerging Location Technologies for Indoor Wireless E9-1-1

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1. Results in Brief

1.1. Executive Summary

The diversity of location technologies reviewed by WG 3 confirms that continual advances are being made in the field. All technologies reviewed lend themselves to hybridization, i.e., the blending of measurements from multiple technologies to increase yield, and possibly accuracy. The work group recommends the establishment of a subsequent Test Bed trial to evaluate future technologies, such as WiFi, GLONASS and U-TDOA for LTE

1.2. Structure of the Working Group 3 Leveraging LBS Technologies

The document is comprised of nine sections and three appendices as follows:

Section 1: Results in Brief
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2. INTRODUCTION

2.1. CSRIC III Structure

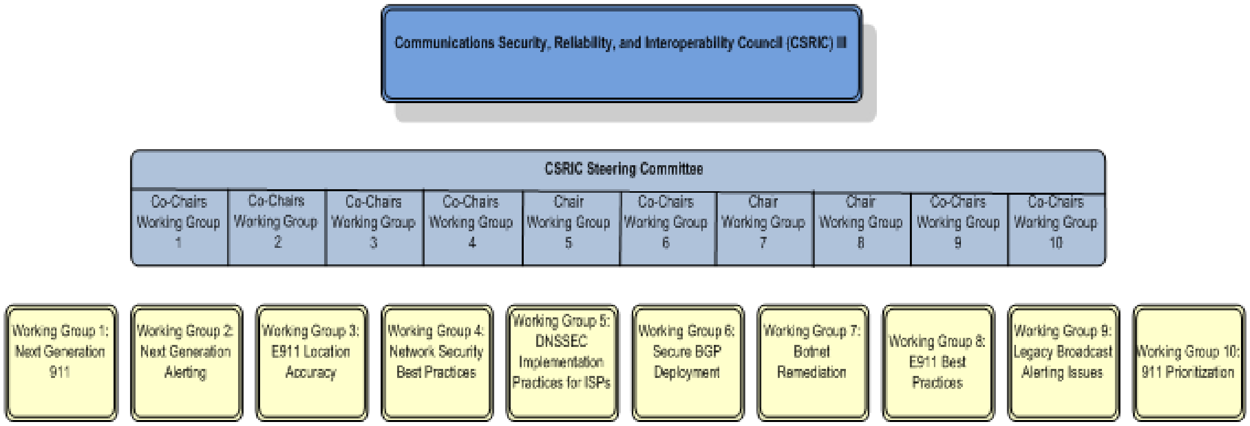

Figure 1: CSRIC III Organization Chart

2.2. Working Group 3 Outdoor Sub-Group Team Members

Working Group 3 Co-Chairs

Stephen J. Wisely – APCO International
Richard Craig – Verizon Wireless

LBS Subgroup Co-Leaders

Ryan Jensen	T-Mobile
Wayne Ballantyne	Motorola Mobility, LLC

Working Group Document Editor:

WG 3 LBS Subgroup consists of the following members:

First Name	Last Name	Organization
Wayne	Ballantyne	Motorola Mobility, LLC
Andrew	Beck	CommScope
Richard	Craig	Verizon Wireless
Khaled	Dessouky	TechnoCom Corporation

First Name	Last Name	Organization
Thomas	Dombrowsky	Wiley Rein LLP
Jeanna	Green	Sprint
Roger	Hixson	NENA
Ryan	Jensen	T-Mobile
Marte	Kinder	Time Warner Cable
Sandra	Lott	CenturyLink
Mike	Loushine	Applied Communication Sciences
Barry	Martin	Boeing
Kathy	McMahon	APCO International
Martin	Moody	Metro Emergency Services Board
Gary	Parsons	NextNav LLC
Ganesh	Pattabiraman	NextNav LLC
Gustavo	Pavon	True Position, Inc.
Raghavendhra	Rao	AT&T
Chuck	Ronshagen	Cassidian Communications
Brett	Schneider	Bexar Metro 9-1-1 Network District
DeWayne	Sennett	ATIS
Norman	Shaw	Polaris Wireless, Inc.
Susan	Sherwood	Verizon Wireless
Girish	Sivaram	TeleCommunication Systems, Inc. (TCS)
John	Snapp	Intrado, Inc.
Dorothy	Spears-Dean	Virginia Information Technologies Agency
Bill	Tortoriello	US Cellular
Greg	Turetzky	CSR Technology Inc.
Bruce	Wilson	Qualcomm Inc.
Stephen	Wisely	APCO International

First Name	Last Name	Organization
Richard Deh-Min	Wu	Nokia Siemens Networks

Table 1 - List of Working Group Members

Additional Contributors:

Ajit Kahaduwe – Nokia Siemens Networks
David Conner – U.S. Cellular
Kirk Burroughs - Qualcomm

3. OBJECTIVE, SCOPE, AND METHODOLOGY

3.1. Objective

The charter for the Leveraging Location Based Services ("LBS") Technologies subgroups reads "The Working Group shall explore and make recommendations on methodologies for leveraging commercial location-based services for 9-1-1 location determination and provide recommendations on the feasibility or appropriateness for the Commission to adopt operational benchmarks that will allow consumers to evaluate carriers' ability to provide accurate location information." This suggests that the FCC has interest in knowing if, for example, Wi-Fi [2] Location methods, now deployed in some Smartphones today, can also be used effectively for Enhanced 9-1-1 ("E9-1-1") Phase 2 location determination.

To avoid limiting the scope of our investigating solely to currently-deployed LBS methods (that are not currently used for E9-1-1), the Working Group agreed that emerging location technologies should also be assessed. This is fitting, since technologies still in development could potentially be used for LBS or E9-1-1 in the future.

It was also agreed that, in the assessment of these LBS or emerging technologies, we should look for potential improvements in both Outdoor and Indoor location performance. Additionally, the capability of a location technology to produce a reasonably accurate Z-height estimate could also be considered as a possible performance criterion.

The areas for consideration are summarized as:

- Survey the landscape of existing LBS and emerging location technologies to identify those which could be extended to an E9-1-1 or Next Generation-9-1-1 ("NG9-1-1") use case.

- Using CSRIC 4C [4] as a baseline, revisit emerging location technologies to determine which could also be beneficial to E9-1-1 location.
- Define an objective, quantitative set of criteria for assessing these location technologies.
- Identify issues associated with leveraging these technologies for E9-1-1 location use.
    - Standardization issues
    - Technical considerations (Location Performance)
    - Business aspects (cost-sharing, relationships)
    - Privacy aspects (who owns the data)
    - Other considerations (Longer term objectives)
    - Merging of LBS Location Data Flow into an E9-1-1 call flow. (Potential impact on "User Plane" location technologies.)
    - Separate discussion of NG9-1-1 Call Flows such as IMS 9-1-1
    - Location Privacy concerns

3.2. SCOPE

Initially, Work Group 3 agreed upon the following scope for this report:

1. Work Group 3 will focus on CMRS provided emergency services. While ideally any new location technology should be able to determine location for over-the-top voice services, the details of this are out of scope.
2. Generation of a Location Fix using commercial LBS services will be covered in this report. Transport of the Location Fix to the PSAP is, however, a Next-Gen topic and outside the scope of WG3.
3. We will not analyze hybrid location technologies per se, but rather focus on each new location technology. The ease with which a given new technology lends itself to hybridization will be considered, however.

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Later, it was agreed that we would add a section 5.4 which discusses hybrid location at a high level, with one example technology described.

3.3. OPERATIONAL PROCEDURES

Working Group 3 sub-group on Leveraging LBS Technologies met every two weeks via conference call(s) to review research and discuss 9-1-1 outdoor location accuracy. The sub-group relied upon members volunteering, with their Public Safety agency's or company's support, to embrace additional work in conjunction with participating in the efforts of the full committee.

Additionally, outside parties were invited by the group to present their location technologies which were deemed potentially useful for indoor location.
Text contributions, as completed, were reviewed, edited and approved by the full participating membership of Working Group 3.

The sub-group conducted over 16 conference calls, and held five multi-day face-to-face meetings in Plantation, FL, St. Paul, MN, Santa Clara, CA (twice) and Washington, DC. This effort was challenging given the responsibilities that each member faced in his/her public, private or other professional endeavors.

4. LOCATION TECHNOLOGY ASSESSMENT CRITERIA

4.1. INTRODUCTION

In this section, we formally present the criteria used for rating the LBS and emergent technologies. These include not only the performance metrics such as accuracy and Time-to-First-Fix (TTFF), but also the environments where the new technologies will be evaluated.

4.2. PARAMETRIC CRITERIA AND OTHER ATTRIBUTES

In general, for any LBS Technology under consideration, the standard performance metrics such as TTFF and Location Accuracy will weigh heavily on the value of a proposed location technology. Regarding Location Accuracy, we will separately classify a location solution in terms of its horizontal (XY) and Vertical (Z) accuracy.

Accuracy Horizontal (XY) and Vertical (Z) uncertainty to the 67th and 90th percentiles. These numbers will only be included in the report if validated in the test bed. If not, then the technology description will include a claim as to whether the vendor represents that their technology does or does not meet the Phase 2 XY accuracy requirements. For Z-height, if not tested in the test bed, the vendor shall report whether or not their technology reports a Z-height estimate.

Yield Phase 2 yield may be defined as the ratio of successful Phase 2 locations over the total number of valid location requests. Valid location requests are those where the call is made from within a service provider's advertised RF coverage area. The duration of the call must last up to 30 seconds before a determination can be made that Phase 2 location has failed. A service provider has up to 30 seconds to compute the Phase 2 location estimate. The test process or PSAP must initiate a properly timed location request to the service provider network to generate a Phase 2 location estimate.

TTFF: Time to First Fix (TTFF), for the purposes of this report, (is) to be focused on the performance of the location technology, rather than the overall time it may take to transmit a fix to a PSAP. The ideal definition would be to measure from the time the user presses SEND after dialing 9-1-1, to the time the location fix appears at the MPC. In terms of practical measurement capability, it may be necessary to measure TTFF differently, depending on whether MS-Based or MS-Assisted methods are used.

Actual TTFF parametric numbers will only be included in the report if validated in the test bed. If not, then the technology description will include a claim as to whether the vendor represents that their technology does or does not meet the OET-71 [1] TTFF requirement of 30 seconds.

Uncertainty estimation (reported to PSAP), Radius of a circle in meters, centered around the reported latitude, longitude, and scaled so that the caller is expected to be inside of the circle 9 out of 10 times (for a 90% confidence level).

UE Impact This addresses the question of what hardware and software changes, if any, are required for the location technology to be included in the User Equipment (UE). In the context of this report, UE refers to mobile devices such as feature phones, smartphones, and even tablets having a CMRS modem embedded.

Carrier Network Impact This addresses the question of what changes or additions to the carrier's network components are required to implement the location technology.

Standards Impact This addresses the question of what changes to 3GPP, 3GPP2, OMA, IEEE 802.11, or other relevant standards are needed to enable a new location technology in a non-proprietary network environment. This typically pertains to data interfaces, content types, or data formats; specific location determination algorithms running on a server or in the UE may be proprietary.

Multimode concerns. Modern UEs have very complex requirements governing the simultaneous operation of the voice call modem and other data channels or Wi-Fi. In general, the voice call is usually given priority. Any new location technology proposed must be able to perform adequately when a voice call is in progress.

Background Power This pertains to additional UE power consumption that would be imposed by the location solution, in order to collect RF measurements or other information that would be needed in case an e9-1-1 call is placed. For example, a Wi-Fi-based solution could require that Wi-Fi measurements be collected periodically, in anticipation of a 9-1-1 call (versus collecting all data during the 9-1-1 call). In the vendor technology sections, parametric claims about background power were not included.

4.3. Database Integrity and Maintenance

Nearly all location technologies used today, and under consideration for future deployment, rely on a database describing the location of fixed beacon objects such as WiFi, or a database to store signal parameters used to compute a location fix in an RF pattern matching method. This section discusses the procedures used to create and/or maintain the database, and attempts to answer the following questions: What are the location accuracy impacts if the supporting location database is not well-maintained? What design or maintenance procedures are implemented to preserve the database integrity? What is the effort and cost of database creation versus maintenance? What is the likelihood that maintenance procedures will be performed in a 9-1-1 context versus a commercial context, if an LBS technology is adopted for E9-1-1 usage?

4.3.1. Wireless WAN Cell ID/Base Station Locations

The location of the base station serves two key purposes in today's E9-1-1 network: it is used as a WPH1 location for call routing, and it is used as a seed position for more accurate positioning technologies such as A-GNSS and AFLT. Additionally, when a Phase II estimate of a 9-1-1 caller's actual location is not available, FCC regulations require a wireless service provider to supply the location of the cell site or base station receiving a 9-1-1 call to the designated PSAP.

This clearly requires a complete and accurate database of cell site locations maintained by the wireless service provider. Other network-based location methods used to estimate a caller's location may also heavily rely on accurate knowledge of cell/sector positions.

Other related configuration data may also be important to providing useful location information to first responders. For example, a service provider may supply an uncertainty estimate along with the latitude/longitude of the serving cell indicative of the cell site coverage radius. Another example would be with the use of location methods which rely on knowledge of the surrounding cell/sector's antenna power levels, heights, orientations, beamwidths, etc.

The integrity of an automatic location determination system depends on accurate and properly maintained configuration databases. This can cause additional accuracy degradations and TTFF delays in addition to those caused by poor RF environments and terrain impairments. In fact, the proper operation of cellular networks in general depends on accurate configuration data. By necessity, wireless service providers have developed various methods to accurately capture, validate, and maintain network data.

Database quality can be monitored and improved, as necessary, by checking over-determined Phase 2 measurements, relative to multiple cell sites, for consistency. When inconsistencies are detected, corrective action is initiated, and the cell site database is checked for both missing records and records with large position errors.

Recognizing the importance of accurate configuration data for automatic location purposes, CSRIC III WG3 developed the following industry best-practice recommendation as part of the Outdoor Location Accuracy Report[3]:

Automated Configuration Database Health Checks (referenced from section 5.3.2.1.4 of [3])

"Current location technologies depend upon accurate configuration data provisioned in the network. Automated checks of configuration databases are utilized to detect missing, illogical, or improper values, and flag issues for rapid resolution. Automated methods to identify configuration database errors are an important part of any quality maintenance approach".

As femtocells, picocells, and other small cells become more ubiquitous, maintenance of the base station database becomes more complex, but also potentially more valuable. As cell sizes shrink, the location of the serving cell itself may suffice for a position estimate for both E9-1-1 call routing and first responder dispatch. In other words, the base station position itself can be a Phase II positioning technology. Maintaining such a database of small and perhaps self-deploying base stations is considered an OA&M task at this point in time, but standards for self provisioned Base Station Almanacs (BSAs) could be created as appropriate

Additionally, in-call signaling of such information is possible; e.g., J-STD-036 Rev C [10] added support for inclusion of the position of the femtocell in the 9-1-1 call signaling. The use of this mechanism for location of small "fixed" wireless network entities is currently being worked with the ATIS/ESIF ESM (Emergency Services and Methodologies) workgroup. Options for the delivery of "actionable" information to public safety, based on very small RF footprints (e.g. WiFi, DAS, etc.) are being investigated and detailed. CSRIC will incorporate the results of the ESIF investigation and will, hopefully, be able to leverage the mechanisms that result in any future testing.

4.3.2. Wi-Fi AP databases

There are three primary methods used to create and maintain Wi-Fi AP databases.

4.3.2.1. Managed Access Points

Many carriers are actively deploying managed Wi-Fi APs as a means of offloading data from the WWAN. Such APs could represent a highly trustworthy and reliable database for use in LBS and potentially E9-1-1, assuming the carriers precisely record and maintain their location in a manner useful to Public Safety.

4.3.2.2. Crowd-sourced Access Point Databases

Crowd sourcing methods for creating Wi-Fi AP databases rely on end-user collection of the location of Wi-Fi APs (and WWAN base stations), typically by enabling GPS when a new AP is observed by the UE. One vendor, Navizon, has represented that their database can be used for E9-1-1, and this claim is discussed below. There are numerous issues to consider in using such crowd sourced databases for E9-1-1, most notably the following two: access to all carriers, accountability, and the integrity of data contained in the database.

One of the main challenges of using Wi-Fi access points for location purposes is the development and maintenance of the ever-changing access point database. Navizon approaches the assembly and maintenance of this database through the use of crowd-sourcing, where users can opt to download the Navizon application to their mobile device, which then scans for nearby Wi-Fi access points and cellular towers. Navizon uses incentives to encourage users to participate in this crowd-sourcing process, providing rewards based on the number of data points collected. They now claim over 1.2 million registered users.

4.3.2.3. Access Point Databases Created from Drive Testing

The Skyhook Wi-Fi Reference database was initially created via drive testing, but its points are augmented by crowd-sourcing methods. Like any positioning system, Skyhook positioning system relies on a collection of known reference points that are used to determine location. The Skyhook Reference Database consists of the identity, signal fingerprint and location of hundreds of millions of 802.11 access points and millions of cell towers. The reference database is built through a systematic method of scanning every passable street and road within a defined geographical area and augmenting that with snap shot captures by mobile devices of their surroundings when they request location estimation. The goal of the reference database is to produce a comprehensive, 360 degree profile of every individual access point and cell tower observed within the coverage area. The reference database can be located locally on mobile devices or can be located on a remote server, or mobile devices have an option to download part of the reference database locally. (It is expected that for E9-1-1 purposes, the remote server method would be utilized.) The Skyhook reference database consists of Wi-Fi access points which are operating at 2.4GHz and 5GHz, and also cell tower locations. The Skyhook Wi-Fi positioning system has also implemented logic to detect and filter out mobile hot spots[1].

To improve the database maintenance, the Skyhook Wi-Fi positioning system also provides an interface for users to correct location of their local access points and increase accuracy of the system for the given mobile device. The relative merit and integrity of this capability is yet to be determined.

4.3.3. RF FINGERPRINTING DATABASE

Database setup

The RF Pattern Matching database is established through the combination of a number of basic inputs. The general development of the database mirrors the carriers own efforts in doing RF propagation analysis on their networks. The inputs include cell site data (LAT/LON, Tx/Rx frequencies, antenna information, etc.), as well as terrain data and building data (usually acquired from a GIS vendor). These inputs are put into a propagation model and an RF propagation "pattern" is established and serves as the foundation of the database. The system is then generally driven to get real-world RF power measurements. These measurements are used to "calibrate" or fine tune the database and the power estimates in the propagation model's "pattern" are adjusted and extrapolated from the calibration data to develop the final RF Pattern Matching database.

Database Maintenance

All digital wireless networks have signal strength or signal-to-interference ratio reporting protocols built into their air interface standards, in the form of call processing messages used to make handover decisions. Signal strength-based position location systems simply exploit the reporting structure that is inherent in all wireless air interfaces. As a phone measures the signal strength from nearby cells, it compiles a list of these measurements and reports them back to the

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[1] A mobile hot spot refers to an operating mode for a smartphone or other Wi-Fi-equipped mobile device where its WiFi transceiver operates as an AP for other Wi-Fi clients, using the 3G or 4G WAN as the backhaul.

serving base station, with the reporting procedure varying from protocol to protocol. These measurements can be correlated to a database of signal strength maps, where the best match indicates the most likely position of the handset. RF Pattern Matching (RFPM) leverages the signal strength measurements described, along with timing information and compares this information with network performance metrics (maps) that are derived from a database of network characteristics and from propagation models.

The "map" used in RFPM is based on an accurate database of transmitter locations, antenna characteristics, and the system frequency plan. The location technology is fairly robust, and small inconsistencies among the data generally only result in minor degradations of accuracy. However, the database must be maintained to insure the best performance and consistency.

The major sources of error and impacts on system accuracy are described in the table below. Most of the errors noted are corrected during the deployment phase and initial accuracy testing and are, therefore, not an ongoing maintenance issue. For errors in the system database that are introduced due to network changes made after system turn-up, the system will trigger an alarm, indicating that maintenance is required. These errors are most often cases of unknown cells and/or frequency plan errors. Accuracy degradation from unknown cell errors is limited to the area near the affected cells. Frequency plan errors are addressed through a Secure File Transfer Protocol (SFTP) connection to the operator's MSC, and a pre-scheduled database comparison and update. This scripted maintenance is generally done on a nightly basis. Table 2 below summarizes the potential error sources, their impacts, and mitigation methods.

Manual database maintenance is required only for new cell site additions to a network. If the cell site growth represents less than 20% of the system base, then simple application of the new cell data to the existing database is sufficient to bring performance in-line with expectations. If there is significant cell growth in a network, or within a portion of the network, then the area should be drive-tested to provide new calibration data for the database (map).

Data Error Type	**Source**	**Accuracy Effect**	**Error Rate**	**Detection**	**Remedy**
Missing Cell	Operator's RF Planning tool	High (location requests may be aborted)	Medium	SMLC Alarm	Request data from operator
Cell Classification (outdoor/indoor/DAS)	Operator's RF Planning tool	High (up to 1/3rd site spacing)	Low	Accuracy Testing \ Database inspection	Site audit
Cell Location	Operator's RF	Medium (proportional to	Low	Accuracy Testing	Site audit

	Planning tool	distance from true location)			
Frequency Plan	NOC\OSS	Medium (locations may have lower accuracy fallback computation)	Very low	SMLC Alarm	Update from OSS

Table 2 – RFPM database error sources, impacts, and mitigation techniques

4.3.4. Beacon Location (Indoor or Metropolitan)

NextNav is a managed terrestrial location network where NextNav builds, deploys and operates the terrestrial NextNav constellation. As part of its service NextNav will create and maintain a database that it will make available to wireless carriers as needed for supporting certain modes of operation on the network.

NextNav ensures the integrity of the database by a variety of means starting with the design and manufacturing of the beacons to their deployment and ongoing maintenance. The NextNav beacons are carefully designed with specific choices of components that are characterized at the component and system level to maintain timing integrity and a signal delay profile across various operating conditions and environments. These delay profiles are then verified as part of the component sourcing and beacon manufacturing process; only units that meet the strict system requirements are passed.

During the deployment phase the installation teams use survey grade GPS receivers to accurately calibrate antenna locations. At most installations, fixed length, factory terminated and calibrated RF cables are used. Sites where cables are cut to length are then swept for their delay characteristics. These installation parameters are recorded and electronically transferred to the NextNav Network Operations Center and become part of the database of beacon information. Further system information such as PRNs, time slots, transmit power, etc., are also provisioned from the Network Operations Center to the beacons. The database used in the NOC is backed up continuously and a web front-end is used by NOC personnel to visualize the database parameters. Database records can be exported to any standard format such as CSV, XML, JSON etc.

NextNav continuously monitors the integrity of the network by employing techniques such as receiver monitoring stations across a metro area that it deploys and which can track deviations from expected values of the NextNav beacons. Other soft techniques such as monitoring of positioning results are also tracked and any deviations from expected values raise alarms which are brought to the attention of NOC personnel and serviced as appropriate.

4.4. Standards Impact

Today the US based, FCC Mandated, wireless E9-1-1 implementation is based on ATIS / ANSI standards, predominately in the form of J-STD-036 [10], but with underlying air interface / core network details fully defined by 3GPP2 and 3GPP. These standards support a range of positioning technologies such as A-GNSS, AFLT / OTDOA, RFPM, and U-TDOA allowing the carriers to select different standardized technologies in meeting the FCC mandate. Such standardization is important as it allows for multiple vendor implementations of any one technology and creates competitive products for the carriers to select from. Thus, for any of these technologies to be considered as a viable option for use in a 911 system, they would need to be fully standardized.

There is also a need to consider the full end to end standards, above and beyond just the mobile / network interactions enabling positioning, including the interface to the PSAPs. This is particularly important since, to date, the positioning technologies have been limited to geographical coordinates in the horizontal domain only. When considering indoor environments the addition of a reasonably accurate Z-height estimate could also be considered, as well as possibly other methods of expressing the position estimate, perhaps with some wire line / civic formats being considered. A large number of standards bodies, such as NENA, ATIS, and IETF might need to be engaged to define a workable end to end solution comprised of many discrete standards.

With the introduction of Z height and potentially other data formats, persistently difficult topics like uncertainty estimation (reported to the PSAP), pertaining to the ability of the location technology to provide a reasonable estimate of uncertainty, which is reliable, usable, and yet not overly conservative, will need to be revisited. Additional complicating factors also include the fact that there are two standards in place today for LTE; the 3GPP Control Plane solution and the OMA-SUPL User Plane solution [7]. The market could be fragmented in the early adoption period, and roaming and interoperability issues may arise.

Also, the data formats supported by PSAPs will also need to evolve. For example, some PSAPs are now incapable of receiving Z-height, and Z-height uncertainty. Moreover, the PSAPs' GIS databases would also need to support Z-height. Therefore, they would need to update their equipment to support this.

Finally, the existing standards in many cases assume a common access service provider and voice service provider. How the existing and new positioning technologies can be leveraged in an "Over the Top" (OTT) voice service provider is an area where additional standards work may be needed. Furthermore, when VoIP over WLAN (potentially from OTT providers) comes under 911 mandates, more and more calls will occur over 802.11 / WLAN networks. As these network deployments are usually less controlled, and the existing standards lack support for things like unauthorized access, those aspects will need to be addressed as well.

4.5. Morphology limitations on specific technologies (e.g., AP density for Wi-Fi location).

Certain location technologies may depend on factors beyond the control of the carrier for them to provide good performance. For example, for Wi-Fi location, the AP density in a certain area will affect the results. In addition, based on ATIS-0500013, factors such as sky visibility, building height, building construction type and material, density of neighboring buildings, as well as cell densities and their geometries, strongly influence the success of indoor location performance.

4.6. Penetration of certain auxiliary technologies in UEs

This pertains to the fact that certain subsystems in cell phones or Smart phones may not be available in all devices. Thus if the location technology depends on this subsystem, only a subset of devices can benefit. For example, Wi-Fi has become popular in many Smartphones, but there are still a significant percentage of mobile devices that still do not have such a feature. If the penetration rate is currently 0%, what UE changes are needed to support it? Often, this requires commitment from the wireless semiconductor industry to include a new sub-system with another existing IC. These vendors will typically not make such a large investment without seeing compelling evidence from a wide range of worldwide customers that adding a new subsystem is needed.

4.7. Business & Institutional Issues

4.7.1. Private Databases

A number of LBS technologies rely on private databases, (e.g., the WiFi-based location providers). These databases are proprietary and confidential, and heretofore have not been openly accessible by Public Safety or the wireless carriers.

4.7.2. Legal/Liability Concerns for using cLBS Location for E9-1-1

Traditionally, location determination for CMRS E9-1-1 services in CDMA, GSM & UMTS networks has been strictly controlled by the service provider using control plane, carrier-managed solutions that ensure the 9-1-1 call is placed using the strongest signal. In addition, the UE is controlled during the emergency call to ensure that no other device functions interfere with the positioning messages between the UE and location determination method, allowing for the best possible location to be calculated and delivered to public safety.

Commercial Location-Based Services (cLBS), on the other hand, have not been subjected to mandated accuracy levels and rigorous compliance testing and evaluation to ensure that database integrity and peak accuracy levels are maintained. Using cLBS for emergency services is problematic because:

- A short Time to First Fix (TTFF) is critical for emergency services location. In traditional CMRS E9-1-1 location (using control plane), network assist is provided to the UE that not only allows for a short TTFF, but also helps the UE see the most GPS and/or network signals possible in challenging environments;
- Another concern is that not all customers subscribe to cLBS, and even those who do may not have the service or their location privacy setting turned on at the moment they make a 9-1-1 call. Moreover, not all UEs will support cLBS applications;
- The UE must handle simultaneous voice and data. This is a limitation for devices and network configurations that do not support simultaneous voice and data; thus a significant proportion of the cell phone users would still be affected for an extended period of time, until their devices are replaced.

Even more problematic would be the use of over-the-top (OTT) commercial location applications that use the carrier networks or Wi-Fi for data transport. In this open access environment, the wireless broadband service providers have no visibility or control in the accuracy, integrity, and reliability of the location provided by these OTT applications.

Utilizing these un-validated, un-tested location methodologies to public safety for use in emergency dispatch, opens up liability concerns for the wireless CMRS provider that need to be considered. Any applications not fully integrated with the carrier's 9-1-1 architecture, which offer 9-1-1 calling, must bear full responsibility for all aspects of delivering Phase 2 calls and location to the PSAP, a recommendation that was also provided in [4].

Should any cLBS location technology appear to be promising enough to be integrated into the carriers' E9-1-1 architecture, it should only be used if it is adapted to adhere to standards-based emergency services position determination methodologies and accuracy specifications. Furthermore, wireless service providers must be able to validate the accuracy, reliability and integrity of the positioning databases and location calculations.

Additionally, if any cLBS location technologies are adopted for E9-1-1, the integration with the phone SW must be performed in a manner compatible with present 9-1-1 technologies. For example, the subsystem needed for the technology to work, e.g., Wi-Fi, must be activated regardless of the user's Wi-Fi settings. This implies that the E9-1-1 location function must be integrated at a lower level out of the user's control, and we cannot rely on a downloadable app to obtain the location for the new technology.

4.7.3. Cost Considerations.

Various current and emerging location technologies have different cost considerations. Potential areas of significant cost include: deployment in the wireless network, operation and maintenance, impact to the handset, and other required independent infrastructure or database development.

Some technologies have relatively low costs upfront to deploy but are relatively costly to operate and maintain. Others have relatively high upfront costs and lower operational/maintenance costs. Some methods have cost implications in the handset, some to the wireless network, and some impact both. Others require infrastructure development independent of the wireless network. Some require the development and maintenance of various databases to operate. Overall, each location technology requires substantial investment in both time and resources.

Carrier and OEM costs impact the cost of service to subscribers. Emergency services resources are finite and must be used responsibly. Given these considerations, it is impractical to change location technologies frequently. New technologies must be somewhat future-proof, efficient to deploy into a high-reliability wireless network without impacting voice/data services, and also efficient to operate and maintain. Technologies that allow costs to be shared across multiple wireless carriers are preferred.

To ensure a healthy ecosystem, location technologies must be standardized and should be available from multiple providers.

4.7.4. Location Privacy Concerns.

Nearly all smartphones with GPS provide the end user with a Location Privacy menu. This allows the user to control whether or not a 3rd party app can access his or her location. The only exception is that, for 9-1-1 calls, GPS or other location methods are activated regardless of the user's privacy setting. Moreover, the GPS location determined during the 9-1-1 call is transmitted only to the PSAP endpoint (using intermediate entities such as the GMLC); other UE apps cannot access it after the call ends.

It is therefore imperative that any new location technology that purports to provide good location accuracy and yield for indoors environments, also adhere to the same privacy principles. This means, for example, that the location technology cannot be downloaded in the form of an application, which would be subject to the user's privacy settings. It could also imply that the new location method SW APIs need to be more tightly integrated into the UE's lower level services, thus necessitating close support from the OS or UE provider.

5. Discussion of LBS and Emerging Location Technologies

5.1. Introduction

CSRIC Working Group 3 sought input from a wide variety of location technology vendors, including those with products currently in the marketplace, as well as technology approaches which are not currently productized, but which are developed to a sufficient level to warrant consideration. Some of these technologies were mature enough to include in Stage I of the test bed trials, the results of which are separately reported, but others were not able to demonstrate and trial their technology in the first phase. Those technologies which were not independently tested were still included in this report to give a broader representation of the technologies and vendors who may provide future benefit to E9-1-1 indoor location accuracy and availability.

While many of these vendors expressed claims regarding various performance parameters of their technology (X, Y and Z accuracy, TTFF, yield, etc), those claims could not be validated through the same process utilized in the independent Stage I test bed. Therefore, the Working Group determined that those unvalidated performance claims should not be included in this report. Vendors were asked, however, whether they could meet a generalized performance criteria consistent with the current TTFF and XY accuracy metrics required for handset –based outdoor location accuracy, and whether or not their technology was capable of providing some measure of vertical location. Although these broader claims still need to be validated through subsequent stages of the test bed, the vendors' assertions are included to give a general indication of claimed performance.

5.2. LBS Technologies now in use, but not currently deployed for E9-1-1

5.2.1. Wi-Fi

The most obvious example of widely spread commercial LBS location technology, beyond GPS based navigation, is the various smartphones and operating system vendors ability to provide low power, on demand coarse position estimates using Wi-Fi transceivers. This is accomplished by collecting RSSI and SSID information from the UE's Wi-Fi receiver, and applying a location determination algorithm using databases of the estimated positions or coverage areas of WWAN base stations and Wi-Fi access points (APs). These databases are usually obtained via some combination of scheduled drive testing and crowd sourcing. As discussed in the cLBS section there are many issues that need to be considered before such databases can be used in a 9-1-1 context.

WiFi Positioning methods have become fully standardized. This can be achieved because both the 3GPP Control Plane solution [6] and the OMA SUPL user plane solution [7] allow for MS-Assisted and MS-Based WLAN based positioning, via support of the OMA LPPe protocol. The WiFi Base Station Almanac (BSA) and the measurements needed, however, must be based on said standards, otherwise some standards changes would be needed. If the WiFi BSA is not integrated within the carrier's network, then a standards-based API would be needed to allow access.

Navizon

Navizon is a provider of a global positioning solution using the known geographic locations of Wi-Fi access points. Navizon's global positioning relies on its own global AP database assembled and maintained by a worldwide community of over 1.2 million users, which covers most urban and sub-urban areas around the world. Navizon licenses access to the database, including location lookup, to third parties, e.g., carriers who may choose to deploy a Wi-Fi location solution.

Navizon can determine the geographic location of a mobile device using the MAC addresses and RSSIs of nearby Wi-Fi access points. The Navizon mobile device SW stack that uses Navizon's access library can submit this information to Navizon's server, which compares it against the global Wi-Fi AP locations database, calculating the device's location in reference to these AP locations. Both MS-based and MS-assisted location methods can be supported.

Given their claimed advantages, Navizon represents that their technology should be considered as a candidate for E9-1-1 location on devices that incorporate a Wi-Fi modem.

Parametric performance claims for location accuracy and TTFF

2D Accuracy: - Navizon represents that their Wi-Fi location technology can meet the FCC's Phase 2 accuracy requirements indoors and outdoors

Z-height accuracy: Z-height determination not supported

TTFF –Navizon represents that their Wi-Fi location technology can meet the FCC's Phase 2 30 second TTFF requirement indoors, based on a Cold Start, i.e., not assuming that Wi-Fi has been powered up before the user places a 9-1-1 call.

Multimode concerns

In most cases this should not be an issue since the Navizon location method does not require Wi-Fi TX activity. Specific scenarios, such as LTE Band 41 co-existence with Wi-Fi, need to be studied in an actual implementation. For Circuit-switched fallback (CSFB implementations) where simultaneous voice and data is not permitted, the Navizon server-based method will not work.

UE Impact

A Wi-Fi transceiver supporting 802.11 b/g/n in the 2.4 GHz band is required. If the Wi-Fi transceiver supports the 5 GHz band, AP measurements in this band can also be used by the Navizon server.

In order for the Navizon to be used in an E9-1-1 location scenario, it is necessary to have a piece of code on the device that will be called when the user makes a 9-1-1 call (not used the rest of the time). This procedure can either be a low-level service that would be installed on the phone or an update to the OS.

Carrier Network Impact

There are two ways to use the Navizon database on the server side:

1. The carrier may elect to tap into the Navizon database by using their Web Service API. When a user makes a 9-1-1 call, the Wi-Fi information is sent to the carrier, which will then send that information to the Navizon server which returns a geographic location.

2. The carrier may choose to have the Navizon system deployed in-house in order to prevent any remote access to the Navizon server.

Standards Impact

Navizon advises that the 3GPP control plane location transport specs for transmission of WiFi measurements, discussed in 5.2.1, could be developed as an optional feature.

Background Power

None required. Periodic Wi-Fi scanning prior to a 9-1-1 call is not needed

Skyhook

The Skyhook Positioning System is a metropolitan-wide location determination system, which combines Skyhook Wi-Fi based positioning system, Skyhook cellular based positioning system, GPS and accelerometer information in order to quickly deliver accurate and reliable location information. Skyhook Wireless claims that their Wi-Fi Positioning System was the first commercial metropolitan-wide location platform to leverage the unique characteristics and wide deployment of IEEE 802.11/Wi-Fi access points for location determination. The Skyhook Positioning system is designed to operate as either a stand-alone positioning system or work in a client-server mode.

The high level view of client and server architecture is shown as follows:

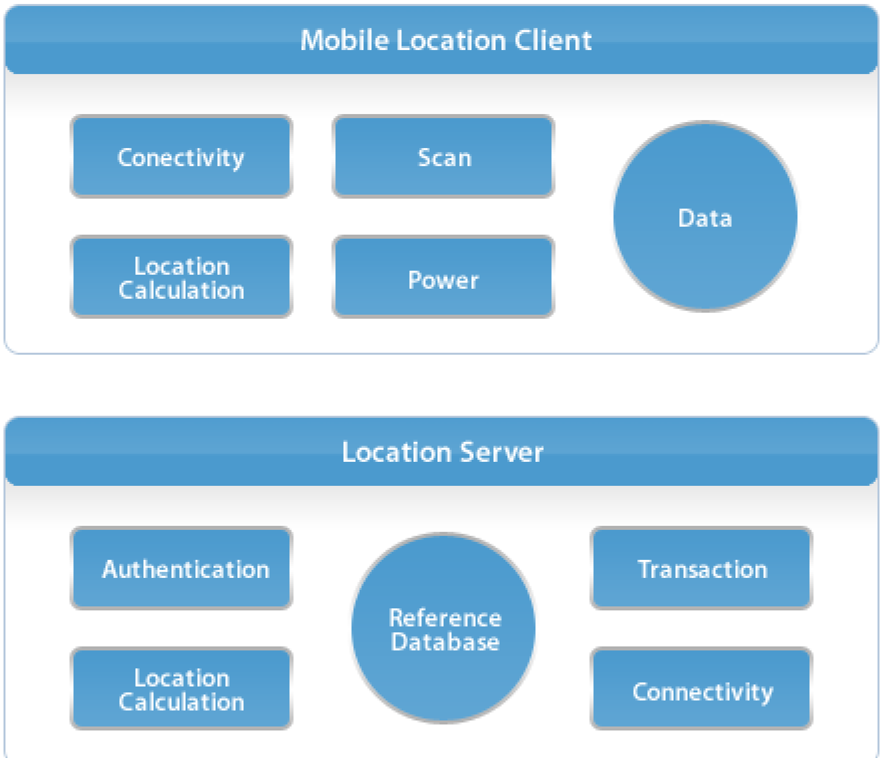


Figure 2: Skyhook Location Architecture

Skyhook positioning technology is described as a complete, fully integrated system managing each element of a location transaction and leveraging all the information available to a mobile device from satellite, cellular, and Wi-Fi based positioning systems and available sensors on the device.

The Skyhook positioning engine consists of:

Skyhook Switching logic, which receives GPS, cell tower, and Wi-Fi access points information and estimates a mobile device location based on aggregated information

Skyhook power management which optimizes usage of different resources of information while trying to maintain the best level of accuracy.

Skyhook cell positioning system which provides location estimate and expected accuracy based on observed cell towers

Skyhook Wi-Fi positioning system is one of the critical components of Skyhook positioning solution, which consists of three core components:

- **Skyhook Wi-Fi positioning Client**: Wi-Fi driver interface that initiates and manages the scanning and collection of, nearby access point data. The Skyhook Client collects key data such as the Media Access Control (MAC) address and Received Signal Strength (RSSI) of each acquired access point and then delivers that information to the Location Engine. The scanning and collection of Wi-Fi access points is done either actively or passively. In the case of passive scanning, Skyhook Client operates in receive only mode, and in case of active scanning, Skyhook Client follows Wi-Fi standards and probes Wi-Fi access points.

- **Skyhook Location Engine**: An algorithmic-based software process that uses the access point data collected by the Client and the corresponding data of known access points in the Reference Database to calculate location. Since every access point in the reference database has a comprehensive and unique 'signal fingerprint', the Location Engine can use that fingerprint – and not just basic reference point triangulation – to calculate location. The Skyhook location engine can be run locally on the mobile device or can be run on a remote server.

- **Skyhook Reference Database:** Like any positioning system, Skyhook positioning system relies on a collection of known reference points that are used to determine location. The Skyhook Reference Database consists of the identity, signal fingerprint and location of hundreds of millions of 802.11 access points and millions of cell towers. The reference database is built through a systematic method of scanning every passable street and road within a defined geographical area and augmenting that with snap shot captures by mobile devices of their surroundings when they request location estimation. The goal of the reference database is to produce a comprehensive, 360 degree profile of every individual access point and cell tower observed within the coverage area. The reference database can be located locally on mobile devices or can be located on a remote server, or mobile devices have an option to download part of the reference database locally. It is expected that for E9-1-1 purposes, the remote server method would be utilized. The Skyhook reference database consists of Wi-Fi access points which are operating at 2.4GHz and 5GHz, and also cell tower locations. The Skyhook Wi-Fi positioning system has also implemented logic to detect and filter out mobile hot spots.

Figure 3 depicts the density of reference points and the geographic expanse of the coverage areas that characterize the Skyhook Reference Database. On average, a Skyhook enabled application operating within a metropolitan area will be in range of 6-9 known access points giving Skyhook positioning system an overlay of Wi-Fi signals that can be used to calculate location.

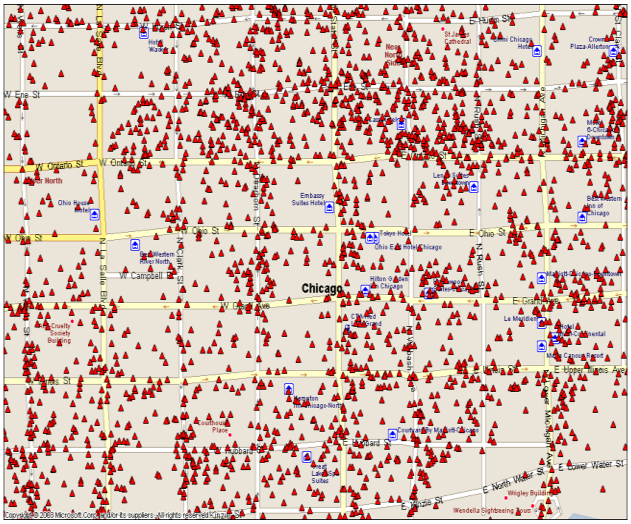


Figure 3: Wi-Fi Access Point Distribution & Density, Chicago

The Skyhook location engine is claimed to be able to deliver accurate, available and timely location determination by leveraging the unique capabilities of IEEE 802.11 access points and cell towers as they are deployed on a wide scale as well as GPS capabilities. Wi-Fi positioning system has a unique role in the Skyhook solution because of:

- **Ubiquity** – 802.11 access points are deployed on a large scale by private and public organizations and individuals - with the most concentrated number in urban, populated areas. This fact enables Skyhook Wi-Fi positioning system to leverage an existing and self-maintained reference infrastructure.

- **Density –** there is nearly 100% 802.11 radio coverage in non-rural areas, including urban canyons and indoors. This provides the Skyhook Wi-Fi positioning system with a large number of reference points that can then be used to deliver exceptional availability and accuracy.

- **Signal Fingerprinting –** each access point creates a unique signal fingerprint based on its environment. The Skyhook location engine uses those unique fingerprints as input variables in determining location. This results in significant accuracy gains.

- **Global Standard –** 802.11 is a well-defined standard that has been adopted and implemented globally, giving the Skyhook location engine the ability to operate universally and independently of the network interoperability limitations.

Parametric performance claims for location accuracy and TTFF

2D Accuracy Skyhook represents that their Wi-Fi location technology can meet the FCC's Phase 2 accuracy requirements indoors.

TTFF –Skyhook represents that their Wi-Fi location technology can meet the FCC's Phase 2 TTFF requirement of 30 seconds, for indoor and outdoor environments. This assumes a Cold Start, i.e., the Wi-Fi has not been powered up before the user places a 9-1-1 call.

Z-height support: Z-height determination not supported

Multimode concerns

The Skyhook location engine not only can concurrently run with cellular modems, but also takes advantage of cell tower positions as another input to the location engine. For Circuit-switched fallback (CSFB implementations) where simultaneous voice and data is not permitted, the Skyhook server-based method will not work.

UE Impact

The Skyhook location system relies on off-the-shelf Wi-Fi devices, and no change to the Wi-Fi drivers is required.

A Skyhook SW component is needed in the UE to collect Wi-Fi and WAN data parameters and transmit these to the Skyhook server, using their custom format.

Carrier Network Impact

The Skyhook location system can compute the UE location autonomously and send it to the appropriate 911 transport network. In practice, if Skyhook is deployed by a carrier also using MS-assisted GPS, the carrier's PDE will need to interface to the Skyhook location server, thus necessitating changes to the carrier's location architecture.

Standards Impact

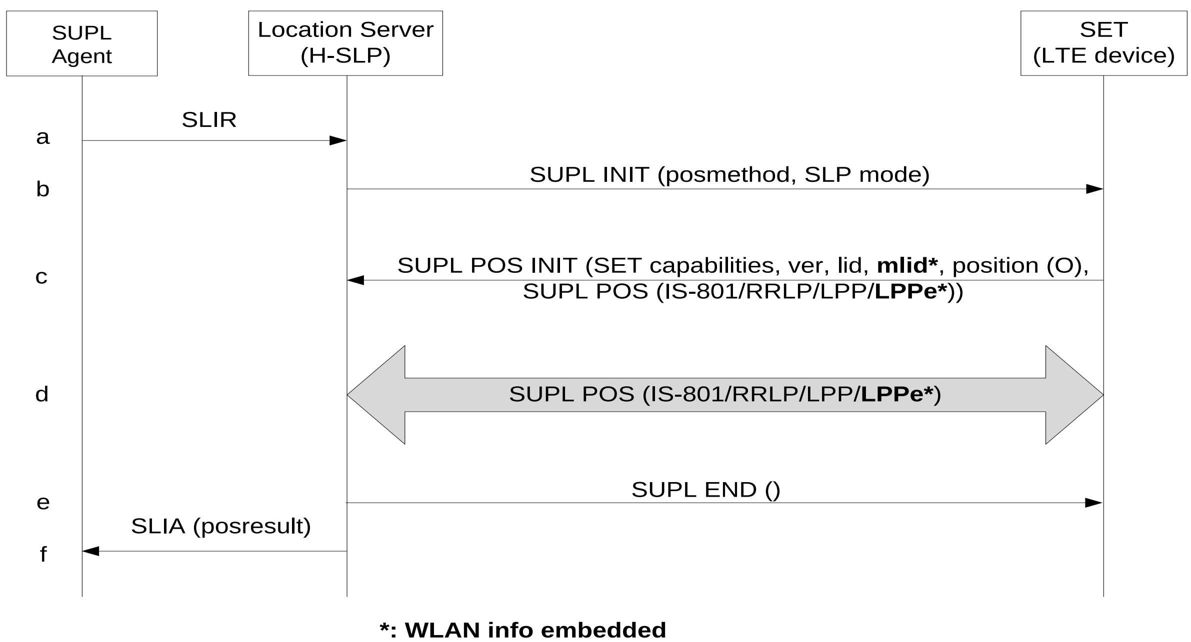
The Skyhook positioning system does not currently conform to SUPL 2.0 or LPPe standards.

Background Power

None required. Because of the short TTFF of Skyhook core location, there is no need for periodic Wi-Fi scanning prior to location request and there is no need for a periodic "keep alive" ping.

5.2.2. User Plane LBS

SUPL is now in use in the US by many carriers, and is fast becoming ubiquitous[2]. SUPL is not a LBS technology per se, but an underlying enabler for commercial location technologies such as GPS and WLAN location, over the user plane. It will be the sole user plane solution for multimode LTE devices. Extending SUPL from LBS to E9-1-1 is important, as SUPL spans multiple air interfaces, including WWAN and WLAN, and supports multiple air interface measurements in a single SUPL session. OMA defined a fully secure E9-1-1 framework that provides all the mechanisms available from the control plane; e.g., non-authorized access, client and server authentication (when an authorized user is involved), data integrity via use of TLS, etc.



[2] *before LTE some carriers, e.g., CDMA, deployed pre standard versions of SUPL*

Figure 4: SUPL message flow for E9-1-1

In the figure WLAN AP identifiers such as SSID and MAC, along with measurements such as RSSI and RTT, can be sent to the location server even if the actual air interface used is WWAN. Similarly, if WLAN is the actual transport, WWAN data can be sent to the location server.

It should also be pointed out that the device can send any current or last known location in the SUPL_POS_INIT message. This can come from a hot GNSS engine, a LBS database lookup, sensors, etc.

5.2.3. A-GNSS

Today many devices use both GPS and GLONASS, as well as the various SBAS systems that exists (e.g., WAAS in the US), but such multi-constellation systems are limited to standalone modes of operations; a full standards based system must be deployed to leverage A-GNSS in a broader context including 9-1-1. Currently, A-GNSS refers to assistance information related to GLONASS, in addition to GPS. In the near future, the Beidou and Galileo navigation system may also be supported. It is expected that A-GNSS will be deployed in the near future, with potential benefit for E-9-1-1. Both Control Plane and User Plane options exists for both LBS and E9-1-1.

The main advantage of additional GNSS constellations in addition to GPS is increased number of available satellite signals for performance gains as follows:

1) Improved availability (of satellites at a particular location) and yield:

2) Improved ability to work in urban canyons and some indoor environments

3) Improved reliability:

4) With extra measurements the data redundancy is increased, which helps identify any measurement outlier problems

5) Improved accuracy:

    a) Better positioning accuracy due to improved geometry (DOP), increased # of line of sight measurements (see [9])

    b) Better positioning accuracy due to improved ranging signals from modernized satellites

(e.g., higher signal strength, longer codes, wide bandwidth signals)

Additionally, A-GNSS functionality can be achieved in a standards-compliant manner, using completed 3GPP standards.

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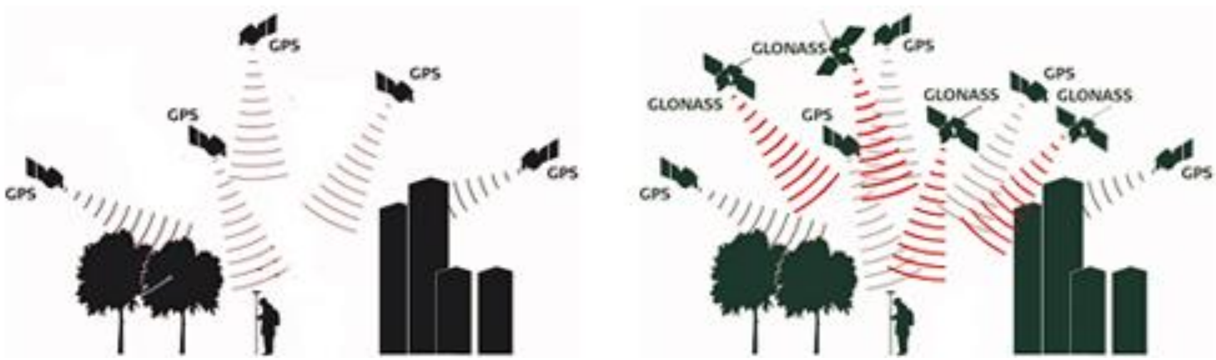

Figure 5: Enhanced satellite visibility provided by GNSS

5.3. EMERGING LOCATION TECHNOLOGIES WITH POTENTIAL BENEFIT FOR E-9-1-1

This section covers location Technologies not yet deployed for LBS, but potentially beneficial for E9-1-1. The criterion for including a technology in this section is that it is well beyond an academic or simulation phase of development, and has been prototyped and characterized in a variety of environments. The CSRIC WG3 sub-group considered all credible technology offerings that they were aware of as of November 1, 2012.

5.3.1. METROPOLITAN BEACON: NEXTNAV

NextNav, LLC ("NextNav") has commenced deployment of a nationwide network of wireless transmitters to deliver a positioning service to cellular and other mobile devices in environments where GPS and other GNSS signals (e.g., GLONASS) are significantly degraded or unavailable, such as indoors or in urban areas.

NextNav's wide-area terrestrial network operates on principles similar to other multi-lateration systems such as GPS, broadcasting highly-synchronized signals. The network sites are placed in and around a given service area in a similar fashion to cellular systems, but with two critical differences. First, while NextNav's sites are typically collocated with paging, broadcast or cellular sites, the specific sites selected are optimized for location accuracy (i.e., horizontal dilution of precision, a metric designed to maximize the angular separation among sites and minimize geometrically induced positioning errors- a common issue with systems, such as cellular, which are optimized for coverage and capacity purposes). Secondly, site density is typically significantly lower than that of cellular communications systems. The transmissions are delivered over NextNav's licensed spectrum in the M-LMS 920-928 MHz band.

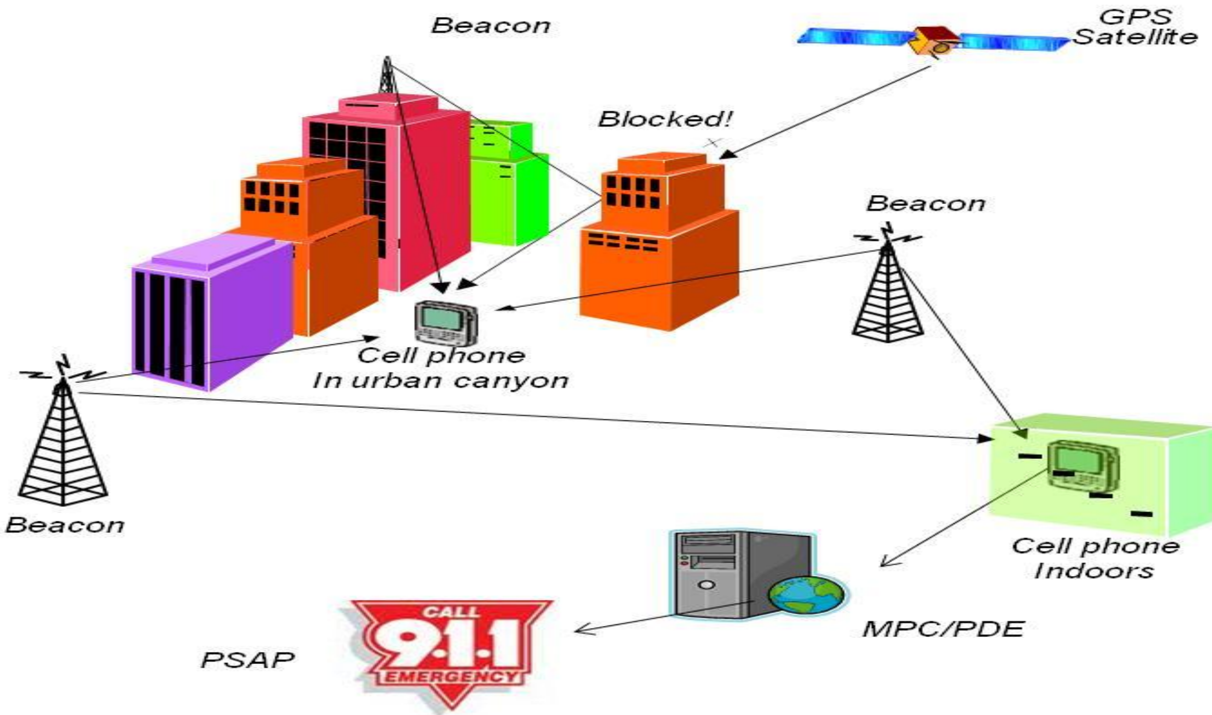

Figure 6: Metropolitan Beacon System Diagram

The NextNav service has been developed as an overlay network – similar to GPS, and is therefore air interface agnostic. In other words there is no impact to the wireless operator and the NextNav system can work with an operator's existing 2G, 3G, 4G or any future evolution of the communication and data network. The concept of a "shared infrastructure" ensures that not only is the cost lower for an operator to receive the service, but also because it's a dedicated location network, so there is an independent path for location service optimization and evolution. NextNav provides a very high level of reliability and redundancy of its network by maintaining a fully redundant beacon – (a Master and Slave transmitter that can switch between them). There is also typically a sufficient density of beacons visible in a given area so that more beacons are available at a given point than minimally required for trilateration.

NextNav has developed two distinct flavors of the technology: the first generation product which is compliant with GPS chipsets, and a second generation higher precision service.

The NextNav 1st Generation service uses an identical bandwidth as the GPS system (2.046 MHz), and uses similar data rates, allowing for standard GPS chipsets to reuse the digital baseband without any changes. However, the GPS chipset will require the ability to tune to NextNav's 920-928 MHz band, which, depending on the GPS chipset, may or may not require modifications to support the signal. The importance of this is that the NextNav signal is processed by the same hardware elements that process GPS signals, significantly reducing the footprint and cost of this solution in a cellular handset and ensuring a separate chip is not required for indoor location. Because NextNav's system uses terrestrial signals, NextNav represents that the TTFF and power consumption are projected to be lower than GPS. The system also transmits localized pressure and temperature information to the phone over its air interface and, by combining this data with an optional commercial MEMS pressure sensor on the handset, NextNav can determine Z-height very accurately, as evidenced in the CSRIC test bed report. Due to the nature of the precisely calibrated, localized pressure information that the NextNav metro network transmits, the accuracy of the system is better than other un-calibrated techniques.

The NextNav 2nd Generation service is currently under development, and is projected to deliver higher precision than its current generation service. The NextNav beacon will be able to support both the systems with a remote firmware upgrade from the NextNav network control center. The 2nd generation service is likely to involve modifications on the chipset.

Parametric performance claims for location accuracy and TTFF

2D Positioning: The NextNav 1st generation system is capable of complying with the FCC's phase II outdoor accuracy mandates and was extensively tested in the FCC Test Bed in the San Francisco market; validated performance in Dense Urban, Urban, Suburban and Rural morphologies. The system exhibited an overall yield of 96% and a cumulative horizontal accuracy of 51 m and 94 m for the 67% and 90% respectively. Based on internal testing by NextNav, the 2nd generation NextNav system is claimed to demonstrate a significant improvement in performance when tested over the same geographic area, and is therefore expected to perform well within the FCC's current phase II outdoor accuracy mandates.

Height: The 1st generation and 2nd generation NextNav systems do deliver a 'Z' height result. The vertical accuracy of the NextNav system was also tested in the CSRIC test bed, and the results demonstrated a cumulative accuracy of 2.9m and 4.8m for the 67th and 90th percentiles, respectively.

TTFF: the TTFF is within the 30 second maximum timeout as recommended in OET-71[1]. NextNav demonstrated a TTFF of 27 secs 90% of the time in the CSRIC test bed. (There is a design tradeoff between speed of fix and accuracy of a position fix, given OET-71's recommendation for a 30sec timeout, NextNav optimized the system for accuracy and allowed the system to compute the location till 27 secs).

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Multimode concerns

Multimode functionality can be achieved similar to simultaneous GPS/voice call modem operation today, using either a dedicated antenna, or an antenna shared with the GPS and 3G modem. Additional components on the handset board such as a SAW filter may be required and are specific to the implementation.

UE Impact

The UE must incorporate a GPS receiver that also supports NextNav technology. This may imply HW or SW changes to an existing GPS-only chipset. Some current providers of GPS solutions for mobile devices are now developing support for NextNav technology, although their implementations were not completed in time for inclusion in the CSRIC Test Bed.

Carrier Network Impact

NextNav typically runs in autonomous mode and does not require assistance information.

Therefore, as a standalone technology; NextNav has minimal carrier network impact. For an A-GPS/NextNav hybridized solution involving a location server or PDE, there would be SW changes required for the server.

Standards Impact

The NextNav system has been designed to minimize the impact on the GPS ecosystem, including the core network infrastructure in a wireless communications system. This is possible because the NextNav system is similar to a terrestrial positioning constellation and can operate similar to 'Autonomous' modes of positioning where minimal cellular network interaction is required. Upon standardization, the beacon network will support both 'non-hosted' (integrated into the carrier's network) and 'hosted' (independent of the carrier's network) modes of operation. In the US, the 'hosted' mode of operation will be the preferred deployment option. In either mode, the network will be capable of supporting 'MS-Based' and 'MS-Assisted' modes of operation similar to AGPS. In MS-Assisted mode the BSA (Base Station Almanac) deployed in the carrier's network will have to be augmented to support the NextNav beacons or an interface to the BSA will need to be defined when the BSA is 'hosted' outside the carrier's network. NextNav is beginning the process of standardizing its "constellation" in 3GPP, OMA and other international standards bodies and will work to have assigned, for the NextNav beacons, a dedicated "GNSS ID" (in RRC, RRLP, LPP, and IS-801 protocols) and to standardize the over the air protocol between the beacons and mobile.

Background Power

No background power is required.

5.3.2. Bluetooth Beacon

The use of Bluetooth Beacon is potentially attractive for Indoor location because Bluetooth is nearly a standard feature on all current cell phones and smart phones. The Bluetooth 4.0 (also known as Bluetooth Low Energy (BLE) technology is ideally suited to create low cost beacons that could be deployed indoors to determine location. The devices have short range (<20m), long battery life (> 1 year) and low cost such that they are well suited to large scale deployment as indoor beacons in homes, malls, hotels, and just about anywhere. Furthermore, the BT4.0 specification is ramping towards very high penetration rates in mobile devices. This combination would enable any BT4.0 phone when it passes by a beacon to determine its location to accuracy proportional to density of beacon deployment. Bluetooth Vendors such as CSR are now offering BLE support in silicon and supporting software.

In CSRIC 4C [4], the WG reached out to Wireless Werx, a company which had developed a product denoted as "SiteWerx" to obtain device location using Bluetooth beacons deployed indoors. As of July 2012, however, per the web site http://www.wirelesswerx.com , the SiteWerx product no longer appeared to be offered. Additionally, another company, Blue Umbrella, published press releases and white papers in 2010-2011 about a similar technology, for use in a commercial setting. Recent attempts to obtain further information from Blue Umbrella have proved futile, however, indicating the technology was not deployed. In summary, at present, the Bluetooth beacon technology does not appear to be commercially available, and should not be included in the Phase I Test Bed performance characterizations. Going forward, the newly formed InLocation Alliance, an industry working group, is attempting to define an architecture for Bluetooth-based location, as part of its charter. This could lead to commercial LBS deployments in the future.

5.3.3. Network based downlink tri-lateration (O-TDOA)

Standards-based deployment based on Positioning Reference Signals (PRS)

The Observed Time Difference of Arrival ("OTDOA") method is based on Reference Signal Time Difference ("RSTD") measurements conducted on downlink positioning reference signals received by the UE from multiple eNodeB locations. In UE-Assisted mode the UE measures OTD's (observed difference of Time of Arrival) between neighboring eNodeB pairs and reports the readings back to an SMLC to calculate the user location via hyperbolic trilateration. Measurements are made on highly detectable Positioning Reference Signals (PRS). This method depends on the LTE Frame timing and reference signal transmissions from all eNodeBs supporting PRS being closely synchronized in time, which is achievable via eNodeB GPS time synchronization, for example. Support for PRS is an optional feature in 3GPP Release 9. There is evidence that many carriers do plan to deploy it in the near term.

Initially, O-TDOA location will be deployed as an UE-Assisted location method. The standards also support UE-Based via the OMA LPPe specification. LPPe can be used in either Control Plane or User Plane deployments.

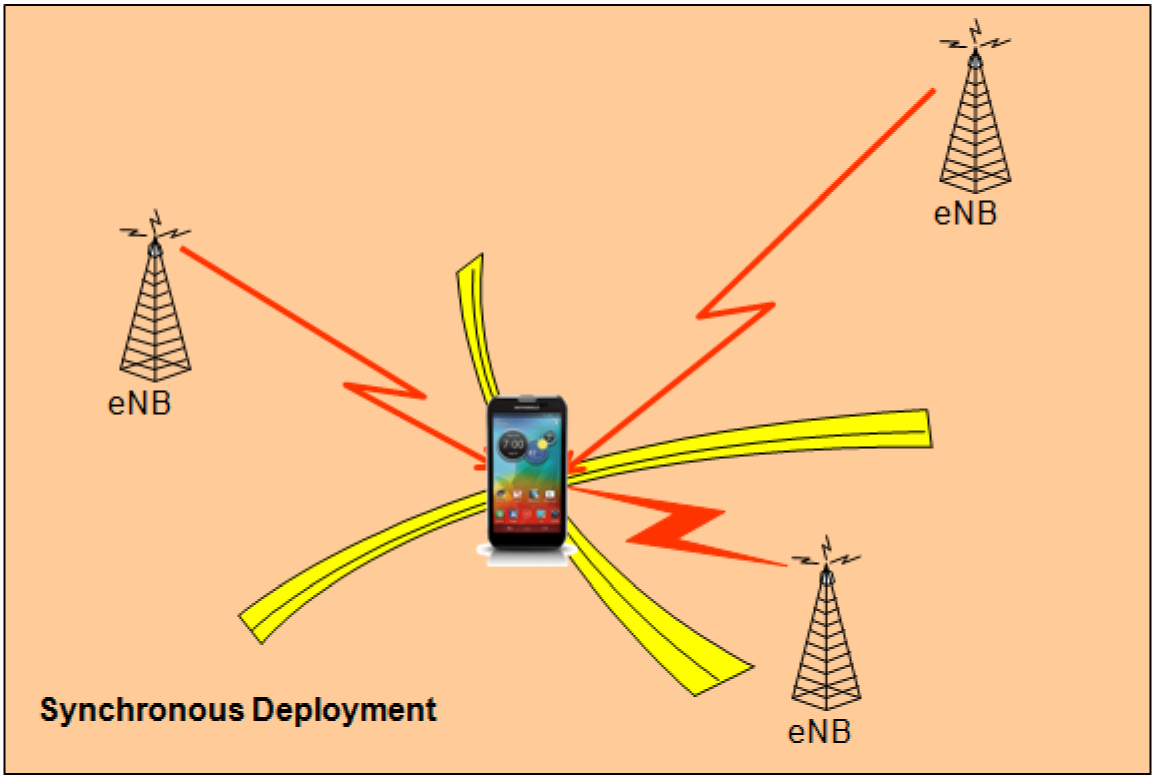


Figure 7: UE Assisted OTDOA Overview

POSITIONING REFERENCE SIGNAL

The Positioning Reference Signal (PRS) is a highly detectable pilot, so transmission of weak cells can be detected and aid the positioning location process. This is achieved by reserving a block of bandwidth in certain time intervals for PRS transmission only. All other channels are muted within the frequency/time allocated for PRS. As mentioned the network needs to be synchronized at the frame boundary and align PRS occasions for all eNBs in time.

ASSISTANCE DATA QUALITY

To perform RSTD measurements, the UE uses OTDOA assistance data as sent from a SUPL SLP or a Control Plane E-SMLC, using in particular the two Key fields mentioned below:

- Expected RSTD – RSTD value that UE is expected to measure between a neighbor cell and the serving cell

- Expected RSTD-uncertainty – Related to the LPP server's a priori estimation of the UE; uncertainty defines a search window around Expected RSTD.

In the figure, cells in the green ring are expected to arrive at UE earlier compared to cells in orange ring. Uncertainty can be estimated based on closest and farthest possible distance with respect to UE's serving cell. Exemplary call flows for both Control and User plane are given in Appendix B.

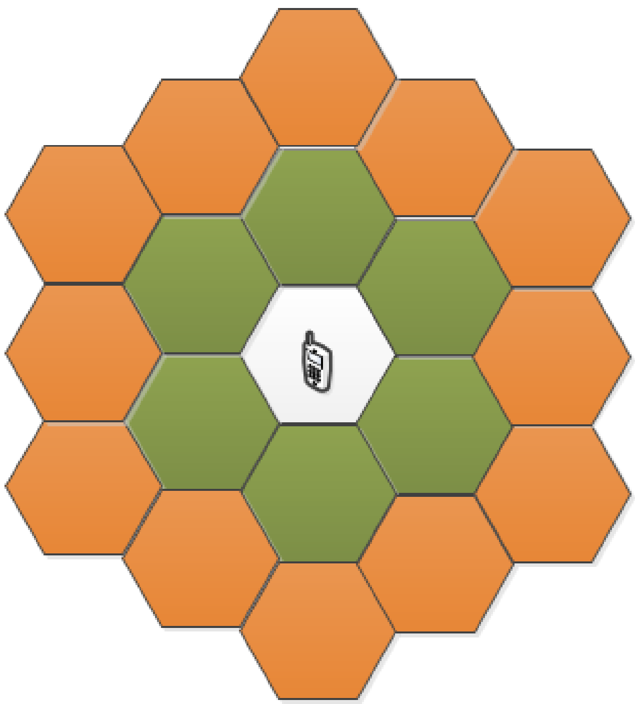


Figure 8: O-TDOA Network Topology

Parametric performance claims for location accuracy and TTFF:

See the Test Bed report for information on AFLT accuracy, which is also relevant to the O-TDOA location solution. O-TDOA developers expect that performance will be better than that of AFLT, due to higher LTE BW, improved hearability, and more advanced processing.

Z-Height

Z height can be determined if there is sufficient Z-height variation among the eNodeBs; the accuracy depends on the cell geometry, but is expected to be coarse.

Multimode concerns

If O-TDOA is deployed only for LTE, it could be used to get a fix in an LTE VoIP or SVLTE (Simultaneous Voice-LTE) scenario, but not in a CSFB (Circuit-switched fallback) deployment where the voice call would occur on GSM, UMTS, or CDMA 1X.

UE Impact

The LTE modem must support O-TDOA pseudo-range extraction for the PRS signals. This capability may not be available in first generation LTE modems; but it is expected that all Release 9 based LTE modems will support O-TDOA in the US.

Carrier Network Impact

There are at least two changes required: (1) the LTE RAN must be configured to support PRS, and (2) the LPP server must be installed. The use of PRS reduces peak LTE data throughput slightly.

Standards Impact

No further changes to 3GPP or OMA are needed to support O-TDOA. The standards for enabling PRS are now available as of LTE Release 9. Inter-frequency O-TDOA is added in Rel 10. UE-Based Mode is defined in LPPe Rel 1.0.

Background Power

None

O-TDOA/U-TDOA Approach offered by InvisiTrack

Multipath propagation is the dominant source of location accuracy errors, especially in challenging environments such as indoors and urban canyons. InvisiTrack has developed signal processing techniques that evolve existing O-TDOA location methods, with advanced multipath mitigation technology and ranging signal processing. This enables InvisiTrack to obtain location accuracy that, they claim, exceeds the FCC Phase 2 accuracy requirements for indoors and in other location-challenged environments.

The InvisiTrack technology can be implemented in one of two ways. The first is a downlink solution, where the UE firmware is modified. InvisiTrack Downlink location methods are compatible with LTE Release 8 Cell-specific Reference (CRS) signals only, unlike other proposed methods which rely on the deployment of Rel-9 PRS (Position Reference Signals). If PRS is present, InvisiTrack will enhance PRS functionality. InvisiTrack can use PRS exclusively or in conjunction with CRS. . The location fix can be determined using MS-based or MS-assisted methods.

For an uplink solution, SRS (Sounding Reference Signals) signals would be used, but the same multipath mitigation and processing techniques would be applied. No UE changes would be needed, but LTE eNodeB firmware modifications would be required.

For LTE, the InvisiTrack approach is to employ LTE reference signals as ranging signals. InvisiTrack location leverages the existing infrastructure by using cell towers, small cells, DAS, indoors signal booster systems, etc., as position reference points. In general, 3 position reference points are needed for a 2-D location determination; 4 points, with at least one of the points located at an appreciable height difference from the other points, are needed for 3-D location

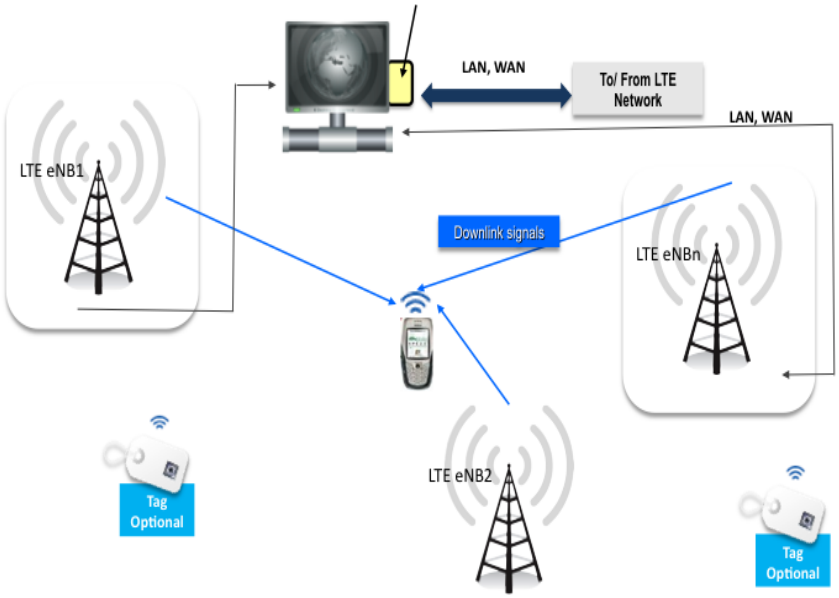


Figure 9: InvisiTrack O-TDOA Network Topology (MS-based scenario)

Parametric performance claims for location accuracy and TTFF

XY Accuracy and TTFF

Using typical LTE signals with a total channel bandwidth of 5 MHz and 10 MHz LTE, InvisiTrack claims e9-1-1 Phase 2 compliant positioning accuracy, and good yield in very adverse indoor environments. This includes highly reflective, scatter-rich environments, such as data centers and college engineering buildings, or in typical indoor environment, such as malls and office buildings.

Time-to-First-Fix (TTFF): InvisiTrack represents that their Wi-Fi location technology can meet the FCC's Phase 2 TTFF requirement of 30 seconds, for indoor and outdoor environments.

Z-Height

Z height can be determined if there is sufficient Z-height variation among the eNodeBs; the accuracy depends on the cell geometry, but is expected to be coarse.

Time-to-First-Fix (TTFF): 0.1 sec (MS-based), <1 second (MS-Assisted)

Multimode concerns

For an LTE VoIP call there will be no issues. If InvisiTrack is deployed only for LTE, it could be used to get a fix in an LTE VoIP or SVLTE (Simultaneous Voice-LTE) scenario, but not in a CSFB (Circuit-switched fallback) deployment.

InvisiTrack technology can be also applied to UMTS; however, at this time the carriers have shown no interest in pursuing this.

UE Impact

There is no impact in an uplink deployment, which would rely on SRS signals sent during an LTE VoIP call.

In a downlink deployment, no HW changes are required for the LTE modem. The InvisiTrack techniques would be implemented in the LTE modem CPU, in firmware or software, with cooperation from the LTE modem provider. . It is important to note that InvisiTrack's solution does not rely on modifying the LTE stack.

InvisiTrack is working with several LTE modem chipset vendors. Modules are expected to be available in Q1 of 2013.

Carrier Network Impact

For the downlink scenario, the impact depends on how much computation is made by the UE. For example, in a case when the UE determines its own location (MS-Based) or computes the Reference Signal Time Difference (RSTD), no changes to the carrier's network are needed other than LPPe support is required. For an MS-Assisted scenario, the position determining equipment (PDE) server SW will need to support the InvisiTrack location methods.

For an uplink deployment, new precise ranging functionality would need to be added to the eNodeBs, or separate LMUs would need to be added to every cell site. Additionally, for an LTE network, the eSMLC would have to be modified to process the uplink ranging measurements collected from the receiving eNodeBs or LMUs.

Standards Impact

For a control plane deployment in the downlink scenario, the InvisiTrack measurement or data set transmission is fully compatible with the 3GPP TS 36.305 standard (LTE Positioning Protocol (LPP).

The uplink scenario requires modifications to the LPPa specification.

InvisiTrack locate can be also supported in a user plane deployment. No changes to the existing SUPL standard 2.0 are needed because specified Positioning payload will accommodate measurements sent by UE.

5.3.4. LEO Satellite-based Positioning: Boeing BTL

The Boeing Company ("Boeing") has developed a new satellite-based technology called the Boeing Timing & Location (BTL) technology. BTL modifies the current Iridium® Low Earth Orbit (LEO) satellite constellation software to enable location in challenging environments, including indoors. Iridium is a global constellation, and can provide ubiquitous coverage across the entire United States, including Alaska and Hawaii. BTL technology is currently deployed on the existing Iridium LEO constellation and is planned for deployment with the next generation of Iridium ("Iridium Next"), thus guaranteeing availability for the foreseeable future.

BTL positioning has several modes:

1) Iridium-Assisted GNSS (IAGNSS) – The BTL signal can assist Global Navigation Satellite System (GNSS) receivers similar to current cellular network Assisted-GPS. In this mode the BTL signal can provide GPS time and frequency aiding, as well as information about GPS satellite orbits (almanac/ephemeris).

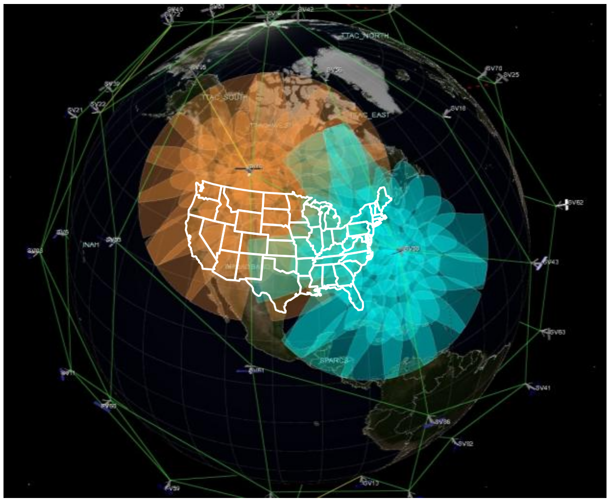
2) Iridium-Only Positioning (IOP) – A BTL receiver can calculate position using just the Iridium BTL signals, i.e., without receiving any GNSS signals. This is a fundamentally different positioning method than GPS, which requires four satellites in view, and uses accurate timing and orbit knowledge to resolve for x, y, z, and time. The Iridium-Only Positioning mode is similar to the retired Navy Transit system which was the precursor to GPS. However, there are many more Iridium LEO SVs than Transit, and current receivers have much better clocks and processing power (Moore's law) since the 1960's. A receiver which receives precise Iridium orbit information and precise time can calculate its position from the unique Doppler shift for a given geometry (Iridium ephemeris/orbit data transmitted to the receiver) and range. LEO Positioning is achieved by sequentially filtering consecutive measurements. For a LEO such as Iridium, each consecutive measurement provides dramatic geometry change. An initial position estimate, formed by several measurements or nearest cell tower location) is updated with each available subsequent measurement. The data transmitted to a BTL receiver can be from the carrier's network, or alternatively, through the BTL bursts. Only one satellite in view is needed to calculate a position; however, at typical U.S. latitudes, often up to three satellites will be visible, which will improve accuracy and time to first fix performance.

3) Hybrid mode – A BTL receiver can calculate position from a hybrid of Iridium and GNSS signals when fewer than four GNSS satellites are in view.

BTL has two chip implementation options:

1) All the BTL positioning modes can be implemented on a Multi-Sensor Chip (MSC) that receives both Iridium and GNSS signals, as well as other sensors such as Wi-Fi positioning and an Inertial Measurement Unit (See the UE Impact section below for more details on chip options). The ubiquitous coverage of both BTL and GNSS signals provides consistent performance across all regions outdoors, and the deep signal penetration of the BTL signal allows the Multi-Sensor Chip to transition to an Iridium-Only Positioning (IOP) mode when the GNSS signals are no longer detectable, giving a consistent performance indoors, across all regions.

2) Another implementation option is an Iridium-Only Chip (IOC) receiver that would implement just the IOP mode. An IOC can either be integrated directly into the phone, or alternatively the IOC can be embedded in a Subscriber Identity Module (SIM) card for a low-power, retrofit capability (see feature item 5 below)



BTL offers several unique features:

1) Ubiquitous Coverage – Iridium's global coverage provides a ubiquitous capability in all counties, urban or rural, for a consistent yield. The figure above shows the Iridium spot beam coverage of just two of the constellations' 66 satellite vehicles. Two satellites completely cover the U.S. and often as many as 3 satellites are in view of a single user.
2) Indoor Penetration – Since the Iridium satellites are much closer to Earth than GPS and the signals received from them are approximately 1,000 times stronger than GPS, the IOP mode enables positions to be obtained deep indoors by geo-locating solely off the Iridium *BTL* signal without the use of any GNSS signals. The IOP mode is available to both the multi-sensor chip and the Iridium-Only chip.
3) No Additional Infrastructure Costs – *BTL* is a handset-based solution that requires no additions to a carrier's infrastructure to implement.
4) Low Power Consumption – A key feature of the Iridium-Only Chip is its extremely low power draw. This low power consumption is possible because of the low duty cycle signal characteristics of the BTL broadcast. The low power draw allows the chip to be "always on" in the background, receiving BTL data bursts, such that when the end user dials 9-1-1, the BTL microprocessor will immediately start calculating a position estimate from the stored data for a quick TTFF.
5) A "retrofit" capability – A SIM card implementation would allow, through a SIM card containing a BTL receiver, an immediate capability through a "retrofit" of currently owned cell phones, versus waiting for cell phone turnover to penetrate a significant portion of subscribers, thereby reducing time to compliance. It should be noted that there are legacy devices that do not use removable SIM cards (CDMA networks), or others where the SIM slot is used only for international roaming. Moreover, some newer devices employ an Embedded SIM which is soldered directly to the PCB. In all of these cases, no BTL retrofit option is possible. Thus, this retrofit capability applies only to those GSM/UMTS/LTE phones that use a removable 2FF or 3FF SIM card (mini and micro-SIM form factors). In this scenario, the phone's chassis is used as the Iridium antenna. The SIM card structure couples to the handset ground plane. By carefully designing the internal filters and matching networks, the handset chassis can be isolated from the SIM card and used as an antenna. While this configuration is not as efficient as a resonant antenna connected to the same chassis, it worked acceptably in tests to date of 5 common handsets. Also, to get the position information residing on the SIM card, changes to the UE firmware or the carrier's E9-1-1 location servers could be required.
6) Consistent Yield – Since none of the BTL modes are affected by tower density/geometry, and the powerful signal is less affected by challenging environments, the BTL solution provides a more consistent yield across all regions.

Parametric performance claims for location accuracy and TTFF:

While it is anticipated that a multi-sensor chip using BTL to assist a GPS chip will have improved A-GPS sensitivity with typical A-GPS accuracies (meters), the IOP mode does not have the accuracy of A-GPS, but it is ubiquitous and can penetrate deep indoors. The BTL system, including the IOP mode, is capable of complying with the FCC *Second Report and Order* [3] Phase II handset-based location technology accuracy mandates. The TTFF will meet the 30 second maximum stated in OET-71, assuming the BTL chip can operate in a background low power mode.

Also, given the ubiquitous coverage, IOP provides a consistent and improved E9-1-1 Phase II yield for every county, regardless of the mobile network operator's infrastructure (tower density/tower geometry).

Z-Height

Boeing has performed preliminary analysis and measurements that supports the ability of *BTL* technology to be able to determine a vertical position as well as a horizontal position. This is possible because the near polar orbits rise and set with varying elevations in the sky, as the earth rotates. Those orbits that have an inclination greater than 45 degrees allow a vertical positioning vector to be estimated similar to the horizontal position. It may also be possible to use the BTL broadcast to provide local barometric pressure corrections for an altimeter based approach. This technology has not been studied in detail with respect to Z-height determination.

Multimode concerns

There are no concerns with receiving the BTL bursts while the phone is operating as the Iridium frequency is not close to the mobile network frequencies.

UE Impact

A BTL receiver ("chip") must be included in the UE to use the BTL signal from the Iridium LEO. There are several possible approaches to get a BTL receiver/chip into the UE.

1. Multi-Sensor Chip (MSC) – A Multi-Sensor Chip can use BTL assistance data (time and frequency aiding, GPS almanac/ephemeris) to support the Iridium-Assisted GNSS mode, similar to cellular network Assisted-GPS. The MSC can also calculate position off of just the BTL

[3] *See* Wireless E9-1-1 Location Accuracy Requirements, PS Docket No. 07-114, Second Report and Order, FCC 10-176 (Sept. 23, 2010).

Iridium signal (IOP mode) when no GPS signal is available in challenging environments. The MSC can also support a hybrid GNSS/BTL mode when less than 4 GNSS satellites are visible.

2. Iridium-Only Chip (IOC) – An IOC can provide positioning using ONLY the BTL signal from Iridium (Iridium-Only Positioning (IOP) mode).

3. Iridium-Only Chip (IOC) integrated into a SIM card (BTL SIM) – A BTL SIM card can integrate an IOC with the other SIM microprocessors to enable a rapid penetration into existing handsets that use SIM cards (GSM/UMTS/LTE such as AT&T or T-Mobile)

Boeing has been working closely with a reputable multi-sensor chip set developer (for mobile devices) who is currently implementing the capability on their next flagship product release. This provider is designing an MSC that can support all of the BTL positioning modes (IAGNSS, IOP, and Hybrid). Boeing has also been working closely with a current provider of low power IC's to develop an IOC. Boeing expects to have both a Multi-Sensor Chip (MSC) and an IOC in 2013/2014 time frame.

Carrier Network Impact

As described above, for a BTL receiver to calculate position, there are several different positioning modes that require assistance data. The different modes need data such as time and frequency aiding, as well as information about Iridium orbits (Iridium ephemeris) and Iridium time biases. This data needs to be passed to the receiver via a cellular network. Modifications to a SUPL server would be required as well as changes to the appropriate standards described below.

Standards Impact

The 3GPP LPP and OMA-SUPL specifications would require modification to support transmission of BTL assistance data (described in "Carrier Network Impact" section above). This server could also provide BTL initialization data, such as a rough initial position (connected cell ID lat/long).

Background Power

A key assumption for the BTL system to provide a fast TTFF is that the BTL chips operate in a background low power mode. As a result, the BTL solution does require some amount of background power. Additional engineering tradeoffs on the amount of bursts received (duty cycle) vs. power consumption have not been performed. Reduced power levels can be obtained in exchange for a reduction in accuracy.

5.3.5. DAS Proximity-based Location

CommScope GeoLENs System

The CommScope proximity detection system is designed for indoor location primarily in environments served by wireless repeaters and/or Distributed Antenna Systems (DAS). The system is comprised of a Proximity Detection Unit (PDU) embedded within or connected to the repeater/DAS controller and detects the serving coverage zone of the target mobile. Zones are defined by the coverage layout of the repeater/DAS system and are typically wings, concourses, or floors of a structure. An example deployment is shown in Figure 10 below. CommScope first deployed this technology commercially in 2002 for E-9-1-1 use and has demonstrated FCC mandate compliant accuracy. The recent market increase in DAS deployments has resulted in renewed interest in proximity detection products.

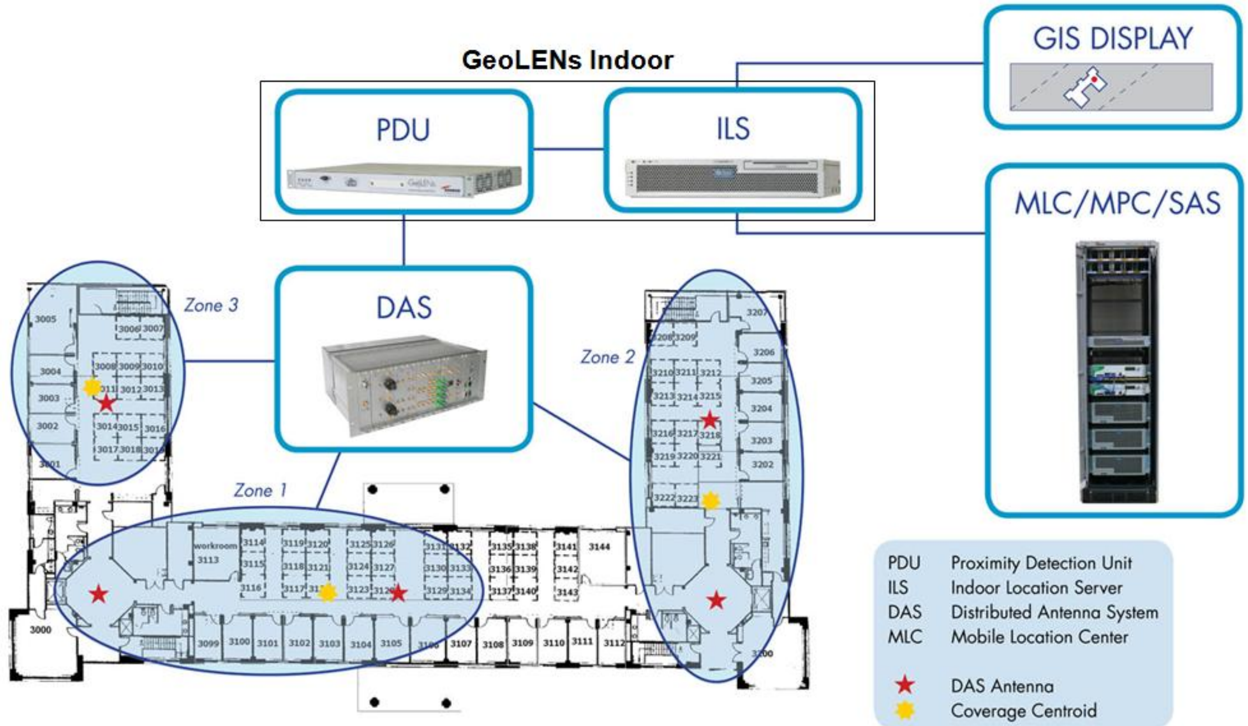


Figure 10 Exemplary Proximity Detection System Deployment Architecture

The GeoLENs proximity detection system is currently available for 2G (GSM) and 3G (WCDMA-UMTS) networks. Support for 4G (LTE) is feasible. PDU’s primarily use signal strength data as collected within the DAS/repeater system to determine a target mobile’s zone. The stronger the signal within a zone, the closer the mobile is determined to be to that zone. The PDU scans and utilizes emergency call signal power from multiple zones simultaneously. Zones are defined by the DAS/repeater system and therefore dictate the location system accuracy. Typical DAS installations place indoor antennas approximately 25 m apart. A DAS zone may be comprised of multiple DAS antennas. DAS venues that cover multiple floors of a structure facilitate 3D location via zone detection. Multiple location requests (e.g. re-bids) may be performed on a target mobile for tracking. Location computation time is dominated by the number of zones the system must scan. PDU’s scanning in parallel minimize this time such that is it typically well under the FCC 30 second recommendation. The system uses 3GPP standard interfaces (e.g. Lb, Iupc) for location tasking and reporting.

The system can be used with CommScope and non-CommScope repeater and DAS products. It also can support multiple wireless carriers. As with many DAS deployments, one installation may support signals from multiple wireless carriers running multiple network air standards. The opportunity for cost sharing among carriers thus exists. Operational cost and complexity is similar to that of a very small LMU system deployment. The GeoLENs proximity system can exist as an underlay to outdoor macro network location systems, providing enhanced accuracy for indoor environments.

Parametric performance claims for location accuracy and TTFF:

The DAS GeoLens system is capable of complying with the FCC Phase II accuracy mandates (for network based solutions). The TTFF is well within the 30 second maximum stated in OET-71.

Z-Height

Possible for deployments where the DAS antennas are on different floors.

Multimode concerns

Since the only technology required for DAS to work on the UE is the wireless modem used for the voice call, there are no issues with other UE sub-systems being used.

UE Impact

None.

Carrier Network Impact

See Figure 10 and the accompanying paragraphs for discussion of the additional network elements required.

Standards Impact

No 3GPP standard changes are required to support the CommScope DAS proximity detection system in GSM and UMTS networks. 3GPP standards committee work is in process for LTE support. The GeoLENs DAS system PDE connects to the carrier network via the Lb (GSM), Iupc (UMTS) or SLs (LTE) interface. The PDE utilizes the tasking and reporting messaging defined by 3GPP in the U-TDOA group. The Lbis interface (ATIS-PP-0700003) is also supported as an option to directly connect to a GSM SMLC in a Remote PDE Protocol (RPP) architecture.

Background Power

None.

DAS Location with RFPM, from Polaris Wireless

RF Pattern Matching (RFPM) technology has been deployed extensively for E9-1-1 services and has been described in a number of CSRIC reports, heretofore. Briefly, this technology leverages a system parameter database (further described in 4.3.3 of this report) and UE measurement information to correlate a matching location for the handset. As RFPM does not depend on exact timing measurements made from the base station or UE (as is the case for Triangulation/Trilateration technologies), this technology is not impacted by ambiguities in the location of received signals on distributed antenna systems. As a result, RFPM provides very good performance in DAS environments. The multiple high energy spots in the RF environment, generated from multiple antennas along with the reported neighbors, reduce the ambiguity area and leads to higher resolution and accuracy in an RFPM location estimate.

The significance of utilizing the unique timing features of DAS propagation environments requires knowledge of the respective antenna head the wireless device is camped on. RFPM has the critical ability to detect which antenna the handset is connected to, without any additional hardware, purely based on uniqueness of the RF signatures and the surrounding information.

Parametric performance claims for location accuracy and TTFF:

The DAS Location with RFPM system from Polaris Wireless is capable of complying with the FCC Phase II accuracy mandates (for network based solutions). The TTFF is within the 30 second maximum stated in OET-71.

Z-Height

Z-height determination is not supported at present

Multimode concerns

Since the only technology required for DAS to work on the UE is the wireless modem used for the voice call, there are no issues with other UE sub-systems being used.

UE Impact

None.

Carrier Network Impact

None

Standards Impact

RFPM uses standard 3GPP messaging and interfaces. The technology has been fully standardized in 2G and 3G and there are no standards modifications required to support RFPM on these air interfaces. The basic messaging and interfaces for RFPM have been completely standardized in 4G as well. The technology will currently operate in 4G, although further enhancements are being worked through 3GPP to better leverage the data capability of this advanced network interface.

Background Power

None.

5.4. Hybrid Positioning

This report, by intent, focuses on individual location technologies and their performance in various indoor environments. When seeking to better understand the technical performance (strengths and weaknesses) of specific location technologies, it is insightful to consider them in isolation (to the extent possible).

In practice, individual location technologies may be combined to improve overall performance (yield and accuracy) across multiple environments. Such a combination is most effective when the underlying constituent technologies are highly complementary (one technology's strengths compensate for another technology's weaknesses).

It is likely that most (if not all) hybrid combinations will include AGPS (or AGNSS) as the primary location method. One key goal of this report is to investigate potential location technologies that might be good candidates for combining with AGPS/AGNSS to improve location performance in various indoor environments.

There are many specific combination options, and selection of these technology combinations will likely vary widely in practice. Individual operators will continue to seek the best technology options, taking into account their unique network, handsets, existing technology investments, economic resources, operational methodology, available standards, and other practical considerations.

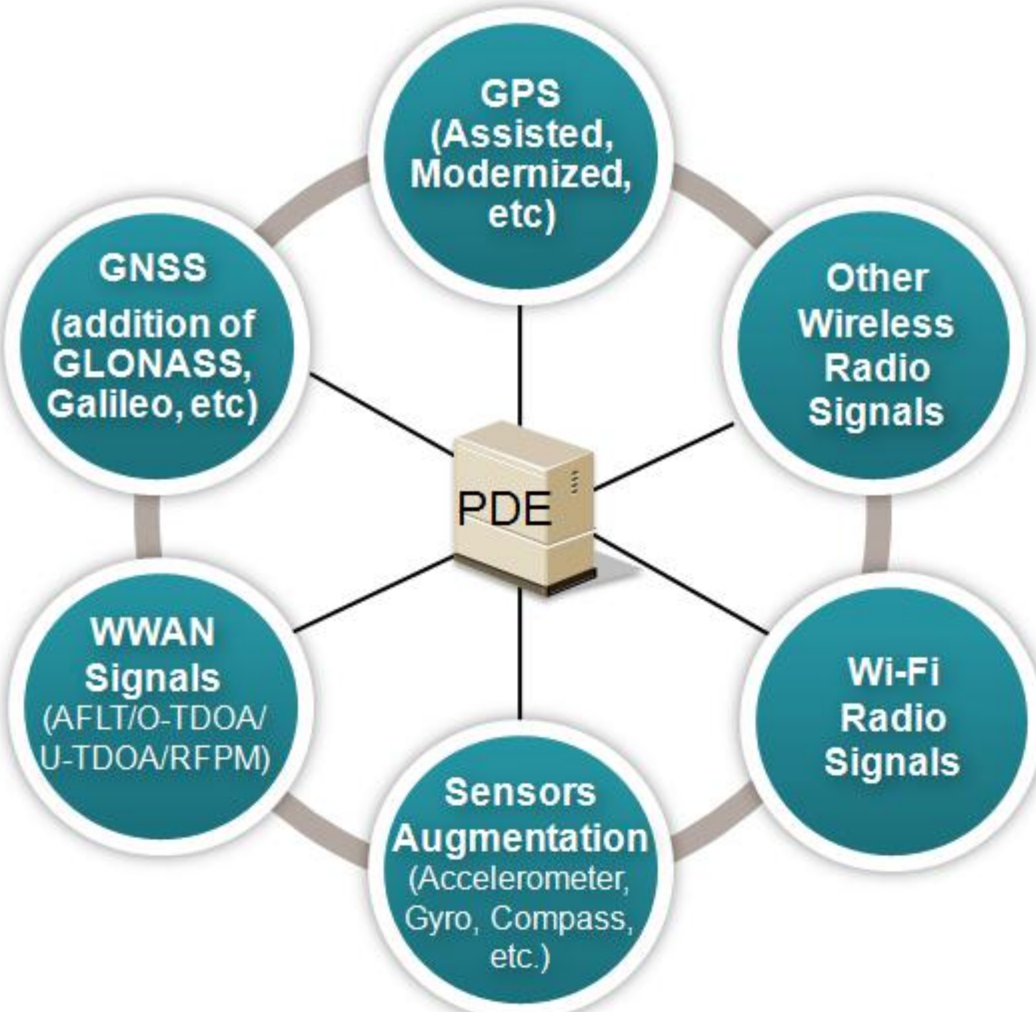


Figure 11: Hybrid combining of measurements for location determination

In the following text, CSR has provided one view of how hybrid could be implemented. This approach utilizes GPS, Wi-Fi, INS sensors such as accelerometers and gyroscopes, and other methods to track user position indoors.

5.4.1. Hybrid Positioning Using Multiple Location and Inertial Navigation Sensors

CSR

CSR, Plc. has expanded its A-GPS navigation capability which is used in e-9-1-1 today, to create a new technology called SiRFusion which is designed to leverage all available measurements from radios and sensors in a mobile device to allow the calculation of position in challenging environments, including indoors. CSR has demonstrated this technology publicly in LBS applications over the course of the past year on several commercially available smartphones. The SiRFusion platform combines A-GNSS measurements with Wi-Fi and MEMS sensors inputs to enable reliable, accurate indoor location. The SiRFusion platform is an end-to-end system that combines a SiRFstarV silicon solution and MEMS sensors in a handset with server-based assistance for GNSS and Wi-Fi.

The SiRFstarV architecture introduces a new approach to location and navigation. Instead of relying solely on GPS to determine position, the SiRFstarV architecture gathers real-time information from GPS, Galileo, GLONASS and Compass satellites, multiple radio systems, such as Wi-Fi® and cellular, and multiple MEMS sensors, like accelerometers, gyros and compasses. It then combines this real-time information with ephemeris data, mapping, cellular base station and Wi-Fi access point location data and other cloud-based aiding information using the SiRFusion platform.

Today, highly accurate outdoor navigation with continuous updates once per second is commonplace. Similarly, until now, using Wi-Fi technology required several seconds to provide a single indoor position fix, which also had relatively low accuracy and a high degree of variability (jitter). By combining real-time Wi-Fi and satellite positioning information, pedestrian dead reckoning (using MEMS sensors) and crowd sourced location and aiding data from a cloud-based server, SiRFusion technology is able to achieve the rapid and more accurate indoor position fixes needed to make continuous indoor navigation a part of everyday life. Unlike many other systems that require manual surveys to build and maintain an indoor Wi-Fi and cellular location database, the CSR Positioning Centre (CPC) cloud-based server is able to receive anonymous and voluntary location information wirelessly from users' devices, even indoors, to continuously improve the database. This fundamentally new approach to location and navigation achieves a seamless transition between outdoor and indoor navigation by combining real-time and cloud-based location information from a multitude of sources and is gaining traction in the LBS market. This technology could be leveraged into e-9-1-1 with appropriate modifications to mobile devices and networks to support it. One example of those modifications would need to address the e9-1-1 location determination process when the user elects to turn off location updates in LBS mode for privacy reasons. SiRFusion could operate in either an MS-Based or MS-Assisted mode on a wide variety of UE platforms depending on a number of factors, including standards support.

Parametric performance claims for location accuracy and TTFF

CSR claims the following accuracy and TTFF data:

2D Accuracy: CSR represents that their hybrid location technology can meet the FCC's Phase 2 accuracy requirements, in both indoor and outdoor environments. The claim for indoor accuracy assumes that a populated Wi-Fi database is available.

Height:- CSR can determine Z-height.

TTFF – CSR represents that their hybrid location technology can meet the FCC's Phase 2 TTFF requirement of 30 seconds, for both indoor and outdoor environments.

Multimode concerns

Multimode functionality is not a concern, GPS, Wi-Fi and MEMS sensors can all be operational during a normal call.

UE Impact

SiRFusion can support a wide variety of UE implementations. A full 10 degree-of-freedom MEMS sensors suite (3 axis accelerometers, gyros, compass and a pressure sensor) is not available in all phones, but most incorporate some subset of these for other uses such as screen orientation and user interface augmentation. SiRFusion will use whatever is available. Most phones also incorporate Wi-Fi, but for those that don't, SiRFstar V can detect Wi-Fi signals without a full Wi-Fi connection.

Carrier Network Impact

SiRFusion currently runs in an MS-Based type mode and can use either control plane or user plane connections for GNSS aiding data and user plane to support other positioning modes. Carrier networks would need to be modified to either support User plane for e9-1-1 or incorporate additional fusion navigation functionality into the server for an MS-A type implementation.

Standards Impact

Standards for positioning would potentially need to be modified to support additional measurement types for MS-Assisted positioning and augment existing standards to report additional information about measurements used in MS-Based methodologies. Some of this work in already underway, e.g., LPPe is developing support for transfer of MEMS sensor data.

Background Power

In order to fully exploit the accuracy and reliability of a SiRFusion navigation algorithm, MEMS sensor data is used on a continuous basis. However, many of these sensors are on continuously for other reasons and therefore require no additional background power. A full characterization of this impact would need to be undertaken. Similarly, the Wi-Fi connection would need to be used to scan for available APs, but this could be done at time of location request.

Test Considerations

The test methodology currently in use by ESIF causes significant degradation in the performance of SiRFusion methodology. In order to create independent results over successive tests at the same location, it is required to clear any memory associated with previous results. This eliminates any benefit derived from the use of MEMS sensors whose main purpose is to track motion between fixes. In addition, SiRFusion uses a self-learned database of Wi-Fi APs that is accumulated as users move about in their normal activity. The first time an AP is encountered by any user, its approximate location is stored in the SiRFusion server database and refined over time and available to other users. For this particular test, the APs in use are not currently populated and therefore the first time the test is run, they will not provide additional measurements but will be added to the Database for the future. This effectively means the first run will not receive any benefit from Wi-Fi. CSR considers both of these items to be related to test methodology and not indicative of performance that would be expected in actual use. CSR considers updating the test methodology for Phase II to be critical to proper measuring of the e-9-1-1 performance of the SiRFusion solution as would be seen in normal use.

6. Specific concerns with usage of commercial LBS technologies for 9-1-1

Per our sub-group's charter, we were asked to specifically analyze the following concerns, related to LBS:

"Identify issues and impediments, and provide recommendations on the feasibility or appropriateness of utilizing commercial location-based services for 9-1-1 location determination.

a. What are the problems?
b. How can the problems be resolved?
c. What are the potential advantages? "

Much of this was covered in section 4.7.2, including concerns about standardization, cost, and liability. What was not discussed is the last question, the potential advantages for cLBS. Clearly, the main advantage is that the basic LBS location technology has already been developed for commercial usage. Thus, the adaptation for e-9-1-1 usage should entail much less development than creating a new e-9-1-1 location technology from scratch. Yet, it must be noted, the pre-existence of a cLBS technology does not ensure that the obstacles and other concerns cited in 4.7.2 can be easily overcome for e-9-1-1 deployment.

7. Summary and Conclusions

The diversity of location technologies reviewed in this report confirms that continual advances are being made in the field. Additionally, all the technologies discussed lend themselves to hybridization, i.e., the blending of measurements from multiple technologies to increase yield, and possibly accuracy. However, very few of these location technologies are currently available for E-9-1-1 use indoors. Three location technologies participated in the Indoor Test Bed. Based on the results, the workgroup believes that good progress is being made in addressing the indoor location challenge; however, significantly more work needs to be done, including characterization of additional technologies in a Phase 2 test bed. The following discussion elaborates on the role of the test bed in the evaluation process, as well as other concerns going forward.

7.1. Role of the Test Bed

In consideration of the charter given Workgroup 3 to carefully study currently available and emerging location technologies and provide insights on expected performance levels in various indoor environments, the group wanted to include specific, quantitative performance data for the various location technologies in the final report to assist the FCC in making informed decisions. It was felt that this further level of detail was necessary to provide additional benefit over prior advisory group reports.

The working group also realized it would be unwise to report specific vendor performance claims that had not been carefully vetted through actual field testing under properly controlled and common real-world conditions, under the auspices of CSRIC. Given these two observations, – the logical way forward was to develop and carry out a common test bed to determine actual performance levels in various real-world conditions, representative of indoor environments across the country. The required test methodology and scientific process for the test bed was jointly developed through a cooperative effort between CSRIC Workgroup 3 and ATIS/ESIF.

The resulting approach was a blind test methodology carried out by an independent test vendor in a mix of building structure types across representative dense urban, urban, suburban and rural morphologies. Geographic contours covering each of these representative morphologies were designated around the San Francisco bay area – deemed to reasonably reflect a wide variety of various indoor environments in a single, fairly small geographical area. Location accuracy, yield, and TTFF were collected as the key criteria used to evaluate the technical performance for each technology.

The goal of the test bed and subsequent report was to provide insights into which technologies are both technically feasible and economically reasonable for providing indoor location for emergency calls.

The following technologies/vendors successfully participated in the Stage 1 test bed:

- AGPS + AFLT (Qualcomm)
- Metropolitan Beacons (NextNav)
- RF Fingerprinting (Polaris Wireless)

7.2. Important Insights Gained in Test Bed process – Summary & Conclusions

The development of this report, and the common indoor test bed process undertaken by Workgroup 3, drove several important insights clearly to the surface, as highlighted in this section. Further details and conclusions from the test bed can be found in the 'Indoor Location Test Bed Report".

Testing indoors presents substantial logistical and technical challenges – as anticipated by Workgroup 3, and highlighted in the 'E9-1-1 Location Accuracy Final Report' [5] In that report, CSRIC WG3 made the following observations and recommendations to the Commission:

- "Indoor location testing is logistically challenging, expensive, and may require differing industry accepted methods of testing", as compared to currently established outdoor methods.

- "Due to the complexity of indoor testing, the working group recommends a flexible and efficient approach that relies on field testing in representative environments".

- "The approach recommended by the working group is to characterize indoor accuracy separately from outdoor accuracy."

- FCC: "Should indoor locations be sampled in a statistical manner within each county of PSAP coverage area? CSRIC: "Consensus within the working group is that such widespread indoor testing would not be practical".

Execution of the common indoor test bed has proven these assertions accurate. Testing in just a single geographical test area required months to plan and execute the tests – even with broad support from vendors, carriers, and public safety. The cost to cover the planning, execution, and analysis of performance within this single test area was also substantial.

Logistical indoor testing challenges include:

- Obtaining accurate ground truth
- Privacy, security, and building access issues
- Large variations in structure types
- Substantial time and cost required to plan, collect, and analyze indoor test data

Technical performance indoors is only one consideration in bringing a location technology into use for emergency services. Other considerations include:

- Commercial availability
- Standardization
- Cost to deploy
- Cost to operate and maintain
- Impacts to the handset

  - Cost
  - Battery life
  - Complexity
  - Size
  - Difficulty validating performance of new handset models
- Impacts to the wireless network
- Availability from multiple sources (versus a proprietary solution)

Seven different location vendors/technologies began the process to demonstrate their performance indoors through the common test bed, but only three completed the process. Of these three, two technologies (AGPS/AFLT and RF Fingerprinting) are already in common use for emergency services, while the third (metropolitan beacons) is not commercially available.

• Significant standards work is required to allow practical implementation of many emerging location technologies for emergency services use.

• While this working group attempted to provide some initial insight into costs associated with implementation of these new technologies – there is much work yet to be done on this front – including further understanding of cost to deploy, cost to operate and maintain, and cost impact to the handset.

Many positioning methods require handset modifications. Integration of these modified handsets into the subscriber base, once the location technology is commercially available, will take years to complete.

Technical performance of some location technologies was determined in the test bed using non-production form factor hardware. Care must be exercised in applying these results to production handsets.

In some cases, determination of the position estimate (position calculation function) for the test bed effort was computed in non-real time, using non-standardized signaling methods. It is assumed these deviations from an actual production implementation do not impact the technical performance of the positioning method.

7.2.1.– Location Technologies/Vendors Not Participating in the Test Bed

The following location vendors showed initial interest in having their technologies tested and highlighted through the test bed process, but ended up not participating in the Stage 1 test bed, for a variety of reasons:

- U-TDOA Positioning (TruePosition)
- DAS Proximity-based Positioning (CommScope)
- AGNSS / WiFi / MEMS Sensor Hybrid Positioning (CSR)
- LEO Iridium Satellite-based Positioning (Boeing BTL)

Other technologies of potential interest for indoor positioning were not available in the Stage 1 test bed time frame, but are good candidates for the Stage 2. These technologies include:

- WiFi-based Location
- A-GNSS (A-GPS and A-GLONASS, and possibly other Satellite constellations)
- O-TDOA with LTE or UMTS

7.3. Recommendation For Stage 2 and Future Test Bed

Location technologies continue to evolve and new technologies continue to emerge. Given the dynamic nature of these technology developments, Workgroup 3 felt strongly that future stages of the test bed should be chartered by the FCC and carried out in a similar controlled manner – perhaps under the auspices of future CSRIC Workgroups. Several cycles of testing, at regular intervals, are needed to support the rate of technology development in this actively developed arena. Thus a test bed management structure, with contractual authority, that extends beyond this and subsequent CSRIC cycles, will encourage ongoing technology development.

Vendors and technologies that chose not to participate in the initial test bed, those who were not identified in time to participate, and other technologies of potential interest (including those listed above) would then have an opportunity to formally demonstrate the indoor performance of their positioning method.

As such, CSRIC Workgroup 3 strongly recommends the FCC consider including the scope for a Stage 2 test bed effort in a future CSRIC charter. It is further recommended that an open invitation be extended to those location vendors who feel their technology is ready for formal public scrutiny, to participate in the next indoor test bed opportunity.

In addition, in order to fully leverage LBS technologies that have different operating characteristics than traditional e-9-1-1, it is recommended that a review of test methodology is conducted before Stage 2 testing. In particular, many LBS technologies assume the location is constantly updated rather than determined on request and this mode of operation needs to be accommodated within the testing paradigm.

New technologies, or significant updates to existing technologies, will require future rounds of test bed characterization. It is envisioned that subsequent stages of the test bed could be run once or twice a year, covering three to four candidate technologies at a time.

8. Appendices

Appendix A, Table of Acronyms

Acronym	***Definition***
AFLT	Advanced Forward Link Trilateration
A-GPS	Assisted-Global Positioning System
ALI	Automatic Location Information
ANSI	American National Standards Institute
AOA	Angle of Arrival
AP	Access Point (usually referring to Wi-Fi)
APCO	Association of Public Safety Communications Officials
AT&T	American Telephone and Telegraph
ATIS	Alliance for Telecommunications Industry Solutions
BSA	Base Station Almanac
CMRS	Commercial Mobile Radio Services
CSFB	Circuit-switched Fallback, a UE architecture option where only a single modem is active at one time, and data connectivity may be terminated when a circuit-switched voice call is placed
CSRIC	Communications Security, Reliability and Interoperability Council
E9-1-1	Enhanced 9-1-1
ePDU	Extended Protocol Data Unit (for LPPe)
ESIF	Emergency Services Interconnection Forum
FCC	Federal Communications Commission
GPS	Global Positioning System
GSM	Global System for Mobile Communications
GMLC	Gateway Mobile Location Center
HW	Hardware
IMS	IP Multimedia Subsystem
KPI	Key Performance Indicator
LBS	Location Based Services
LPP	Location Positioning Protocol

Acronym	*Definition*
LPPe	LPP extensions (used in SUPL)
MPC	Mobile Positioning Center
MSC	Mobile Switching Center
NENA	National Emergency Numbering Association
NG9-1-1	Next Generation 9-1-1
OET 71	Office of Engineering and Technology Bulletin No. 71
OMA	Open Mobile Alliance
OTT	Over-the-Top (here, a reference to 3rd party VoIP applications)
PDE	Position Determining Equipment
PSAP	Public Safety Answering Point
RF	Radio Frequency
RFPM	Radio Frequency Pattern Matching
RRC	Radio Resource Control
RTT	Round Trip Time
S/R	Selective Router
SMLC	Serving Mobile Location Center
SUPL	Secure User Plane
SW	Software
U-TDOA	Uplink Time Difference of Arrival
WAN, WWAN	(Wireless) Wide Area Network; in this report it refers to the CMRS 2G, 3G, or 4G wireless network.
WG3	Working Group 3
Wi-Fi	Wireless Fidelity
WSP/SP	Wireless Service Provider/Service Provider

Appendix B, LPP Call Flows

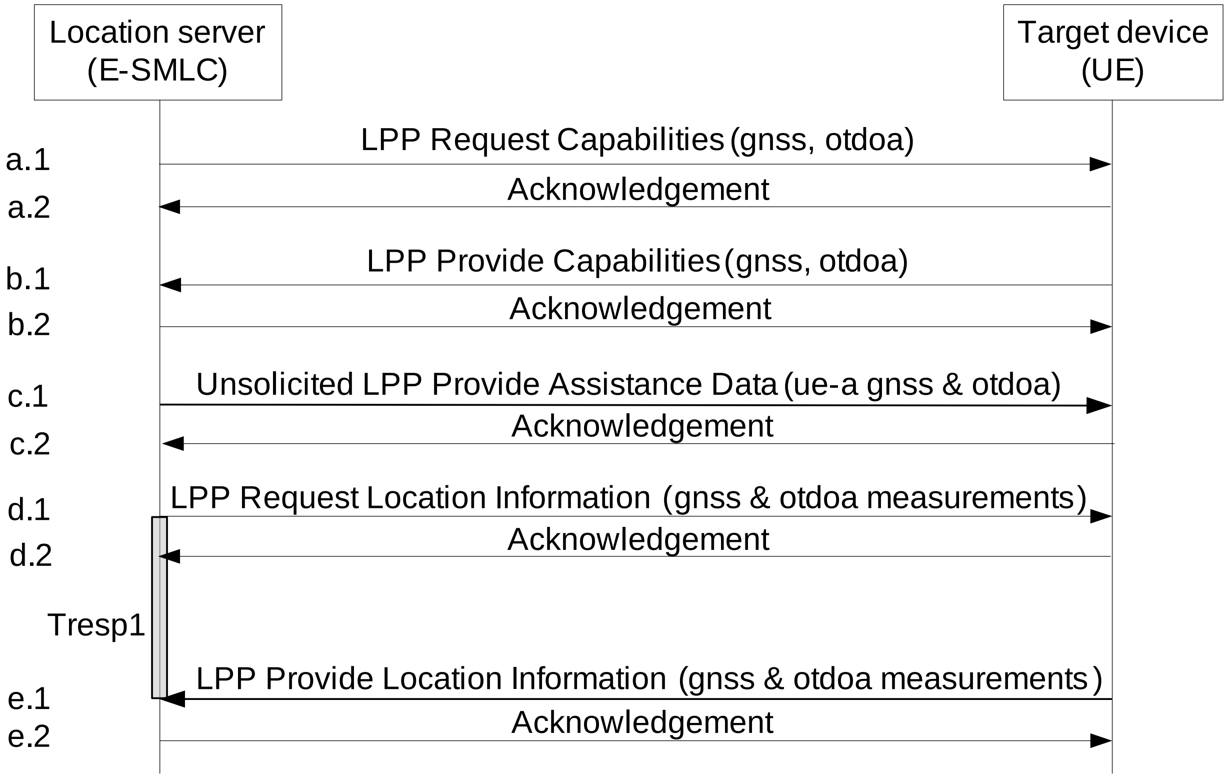


Figure 12 E9-1-1 Control Plane LPP Call Flow

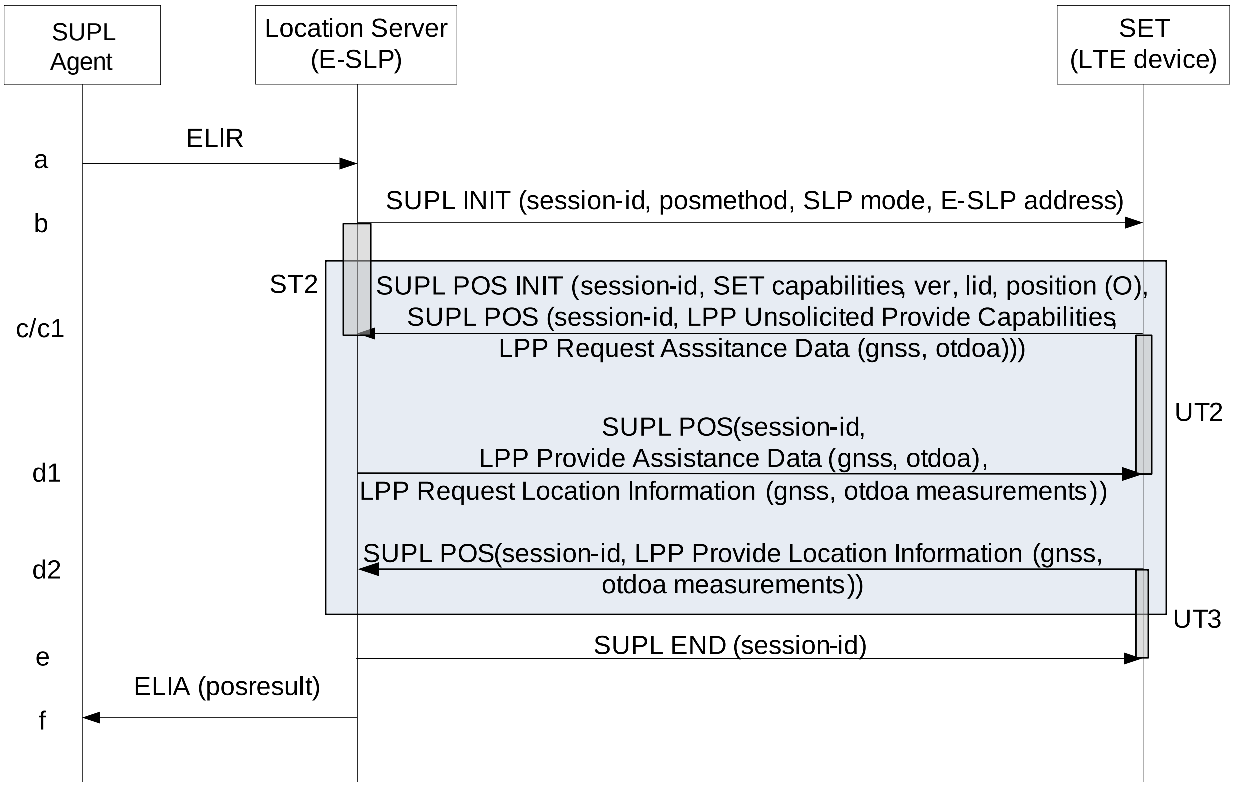


Figure 13 E9-1-1 User Plane LPP Call Flow (UE-A Hybrid A-GNSS/OTDOA)

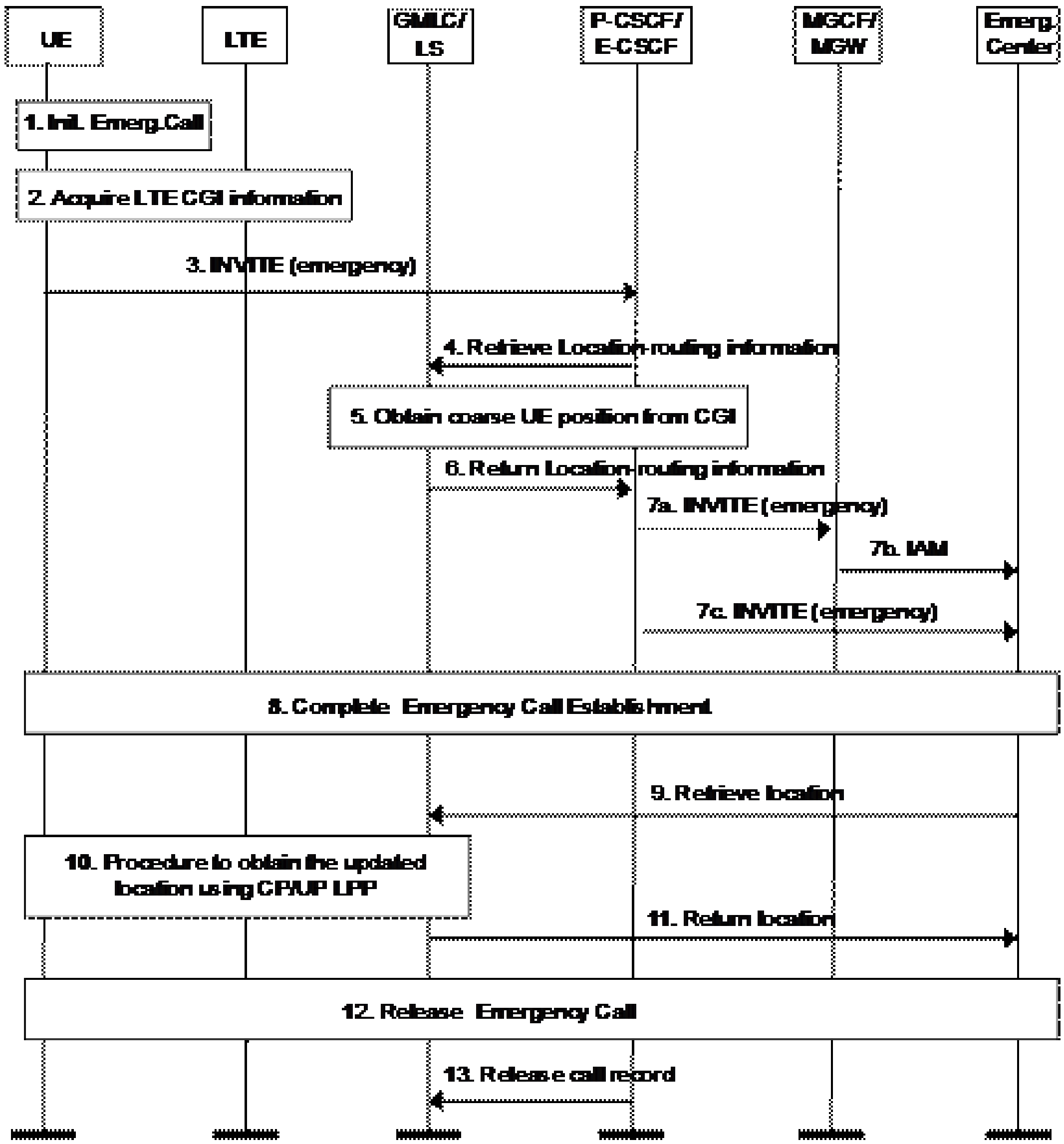


Figure 14 IMS VoLTE E9-1-1 Call Flow

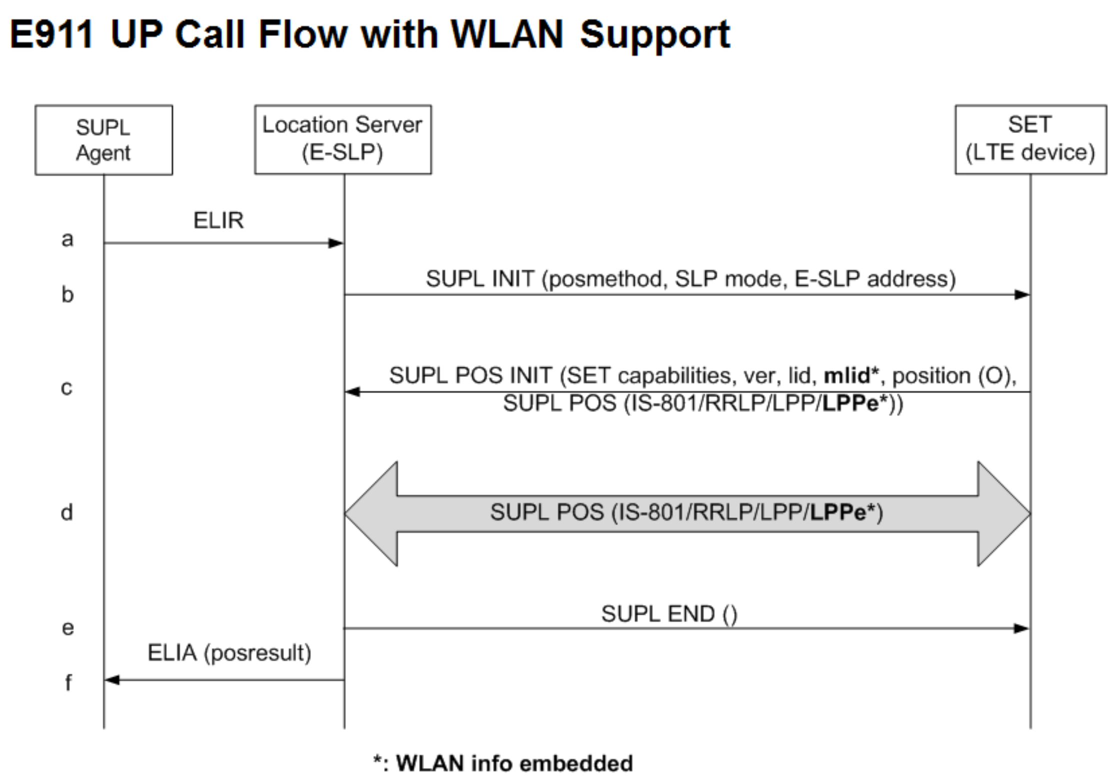


Figure 15 E9-1-1 User Plane Call Flow with WLAN Support

Appendix C, References

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